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THE

NÁGPÚR WATERWORKS;

WITH

OBSERVATIONS ON THE RAINFALL, THE FLOW FROM THE GROUND, AND EVAPORATION AT NÁGPÚR;

AND

ON THE FLUCTUATION OF RAINFALL IN INDIA AND IN OTHER PLACES.

BY

ALEXANDER RICHARDSON BINNIE, M. Inst. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E.,
SECRETARY.

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THE
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SESSION 1874-75.—PART I.

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November 10, 1874.
THOS. E. HARRISON, President,
in the Chair.

No. 1,398.—"The Nágpúr Waterworks; with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nágpúr; and on the Fluctuation of Rainfall in India and in other places."[1] By ALEXANDER RICHARDSON BINNIE, M. Inst. C.E.

NÁGPÚR, the capital of the Central Provinces of the Indian Empire, is situated in 21° 9′ N. latitude, and 79° 11′ E. longitude, at an elevation of from 975 feet to 1,015 feet above sea level. It is 10 miles distant from the Kanhan river, one of the principal tributaries of the Weingunga, a confluent of the Godavery, and 519 miles N.E. from Bombay, on the Great Indian Peninsula railway, being at the extremity of one of the branches of that line. The geological formation of the district is trappean, with basaltic eruptions rising into low rounded hills, and in some places, as at Sítábaldí, the hill fort of Nágpúr, into abrupt eminences. The city, however, is mostly built on gneiss and other metamorphic rocks, of apparently older formation than the basaltic and trappean series which overlie them. The average annual rainfall for the nineteen years 1854–5 to 1872–3 (Appendix, Table I., page 24) was 40·73 inches. Of this amount 37·52 inches fell during the monsoon months of June, July, August, September, and the early part of October, and the remaining 3·21 inches in showers during the rest of the year. By the census of 1872, the population was 84,000; and from older records it is believed not to be upon the increase.

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[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

Up to the time of the completion of the works about to be described, the inhabitants of the city often suffered severely in consequence of the scanty and impure nature of the water supply. It appears from an official return, made in 1864, that out of twelve hundred and thirty-one wells sunk in the basaltic and metamorphic rocks on which the city is built, about nine hundred yielded brackish water; and even those yielding fresh water are thought to have been contaminated by the main drain of the town. Besides wells, there were two other sources of supply—the Jumá Taláo, an artificial tank or reservoir, between the native town and the civil station (Plate 1, Fig. 1); and an old and decayed work, fed from a reservoir at Ambájharí, 4 miles from the city. The former of these sources was not sufficiently elevated to command the city, and the water was unfit for drinking owing to the drainage area being thickly inhabited; the latter source will be again referred to.

During the dry season following the failure of the rains of 1868, the evils of the then existing state of affairs became painfully apparent. The Chief Commissioner, Mr. J. H. Morris, C.S., having determined to remedy them, the Author was directed to prepare a project for furnishing the city with a pure and abundant supply of water. The question had before been the subject of discussion, and several proposals had been made as to the best direction in which to look for a source of supply. The various suggestions were carefully inquired into, and the whole of the country was examined in detail.

The points to be considered were, as all the streams dry up after the termination of the rains, that a good project must include a large storage reservoir, because the subsoil water, owing to its frequent brackishness, could not be used; that the reservoir should be situated at a sufficiently high level to command the city, and be of such capacity as to provide for years of fluctuating rainfall, and for periods of more than one year during which it might remain below the average; and that the reservoir should receive the drainage of a tract of country large enough to yield, even under the average rainfall of the three driest consecutive years, a sufficient supply for the wants of the city, and to provide for evaporation during the dry months.

The result of this examination led the Author, in November 1869, to advise that the old reservoir at Ambájharí should be remodelled and enlarged, and that the water should be brought to the city in cast-iron pipes under constant pressure. These recommendations, having been approved by the municipality and the local officers, received the sanction of the Government of India in April 1870.

The old works, which formed the basis of the project, were constructed under the Bhonslá dynasty (Rajhas of Nágpúr), about eighty or ninety years ago, principally for the purpose of supplying the palace, and the houses and gardens of a few of the native gentlemen attached to the Court. The site of the reservoir is at a point on the river Nág, which flows through and gives its name to Nágpúr, a little to the south-west of the village of Ambájharí (Plate 1, Fig. 1), which name literally means the spring of the mango grove. Perhaps the existence of some natural springs at this place may have led to the selection of the site; at any rate, the Author can state, from personal observation, that even when there was no water in the old reservoir, springs did exist in the low ground below the embankment, and provision appears to have been made for securing the water flowing from them, when other sources of supply failed.

The ancient reservoir was formed by an embankment, rather crooked in its alignment, and 856 yards in length (Plate 1, Fig. 2), across the valley of the Nág. Its average height was 12 feet, the extreme height being 20 feet. Its width at the top varied from 40 feet to 60 feet, and the back slope had an inclination of about $1\frac{3}{4}$ to 1; the inner face was protected by a vertical rubble wall, with projecting semicircular and octagonal bastions, also of rubble masonry. The reservoir, when full, had an area of 237 acres, and contained 80,000,000 cubic feet. The water was drawn from it through a masonry sluice, the flood waters being discharged over two waste weirs, of the aggregate length of 128 feet. Another sluice, 200 feet south of the one in work, had been stopped up, but a good deal of water leaked through.

The Ambájharí reservoir was dry during April and May 1869. The Author then examined the face wall, which was cracked in many places, and showed other signs of unequal settlement, and at the same time tested, by digging holes in the bed of the reservoir, the amount and nature of the deposit since its construction. This was clean earthy matter, in no case of a greater depth than 2 feet 6 inches. The old sluice (Plate 1, Figs. 3 and 4) projected several feet beyond the face wall, and was flanked on the sides by stone steps. The discharge of water was regulated by wooden plugs inserted in five holes in the steps of the outer face, and in seven holes in the side of the well or chamber A. The flow into the city through the masonry pipe was further regulated by another series of wooden plugs in the chamber C; and the water could at any time be cut off from the city by inserting one plug in the outlet of the well marked B. The sluice was generally worked by opening the upper submerged plug on the outside, so as to keep the water in the well A a few feet lower than that in the reservoir as well as one of the submerged plugs in the well A, so that the water did not rise more than a foot or so in the well B; and this arrangement was repeated in the well or chamber C. In the south side of chamber C there was another opening, for the purpose, as explained by one of the old native watermen, of collecting the water from the springs below the reservoir, which often flowed, even in dry seasons, when the reservoir was empty; but in 1869 the channel leading to it was choked.

The pipe from the chamber C to the city was 4 miles in length, and was formed of blocks of sandstone, from 2 feet 6 inches to 3 feet 6 inches long, and 18 inches to 2 feet square, through which a circular hole 9 inches in diameter was bored (Plate 1, Figs. 5 and 6). At one end of each block there was a recess and at the other end a projection, and the joints were made good with mortar, in which a little chopped hemp or cotton had been mixed; the whole of the blocks were surrounded by basalt rubble masonry to a thickness of from 1 foot to 18 inches. The alignment and levels of the pipe track were somewhat irregular. Frequent water towers or cisterns allowed of the disengagement of air, but their principal use was to reduce the head of water, which escaped when required, by openings in the sides of the tower, closed by wooden or masonry plugs. In this way the available head to overcome friction in the last 3 miles of the pipe was reduced to 1 foot. The distribution in the city was on the intermittent principle, the water from the reservoir being delivered into small cisterns (Plate 1, Figs. 7 and 8), in the bottom of which were several holes leading to the service pipes of unglazed earthenware. The water was in turn admitted to or shut off from these pipes by the insertion of wooden plugs in the holes. The design of these old works exhibited much care and skill, principally with a view to accommodate the pressure of the water to the strength of the pipe.

In 1868-69 the whole of the earthern part of the embankment and of its slopes was covered with trees and bushes, and the water leaked in many places from the toe of the outer slope. This leakage, joining with the flow of the springs, had caused a swamp just below the bank, which was covered with rank vegetation, and was dangerous to walk or ride over, being full of holes and boggy places. Trial pits having been sunk outside the embankment, it was found that the rock floor of the valley was covered to a depth of from 3 feet to 14 feet with sand, gravel, and other more or less porous material; and it was evident that the water made its way from the reservoir under the embankment, as it rose in, and flowed out of, these trial pits in considerable volume. The masonry pipe was also in a ruinous condition; the soft sandstone had been broken and repaired in many places, and had become very friable; a bright green vegetation flourished around the leaky places; and internally the pipe was choked by weeds brought down in the water when the reservoir was low, and by the roots of trees. Hence, owing to leakage, both surface and subsoil, and to the evaporation to which so shallow a sheet of water was exposed, the reservoir, as in 1869, was occasionally dry during the hot months, when water was most required; and even when the reservoir was full, the old stone pipe could deliver but a small supply in the city, and this was continually shut off to effect repairs, &c.

The Author selected these old works because above the reservoir there was a catchment area of 6·6 square miles (Plate 1, Fig. 1), free from cultivation and but slightly covered with soil, the geological formation being nodular trap and other associated basaltic rocks. The site of the ancient reservoir also afforded the most economical storage ground, and its level and distance from the city were such as to enable gravitation works to be constructed within the means at the disposal of the municipality.

The works consist of:—A puddle trench through the old embankment, extending at least 3 feet into the rocky floor of the valley. The embankment has been raised 17 feet 4 inches above the level of the top of the old face wall, and a puddle wall constructed to within 3 feet of the full height of the new embankment. Inside the reservoir a straining and regulating tower has been built, and a syphon discharge pipe laid from it over the top of the old embankment, and below the level of the newly raised portion, with a valve house at the foot of the outer slope. A new waste weir at a level 13 feet 4 inches above those of the old reservoir, and a main pipe 4 miles long and 13 inches diameter, with 10,500 lineal yards of distribution pipes of 12 inches diameter, and downwards, have also been provided. The result is that a reservoir, containing a gross quantity of 257,500,000 cubic feet of water, and an available storage of 240,000,000 cubic feet, or 1,500,000,000 gallons, has been formed, the top water area of which is 370 acres. It is calculated that, with this amount of storage, a supply of 15 gallons per head per day of twenty-four hours can be maintained even in years of extreme drought.

While the works were being carried out the water was retained in the old reservoir to keep up, as long as practicable, a supply through the old stone pipe. Active operations were commenced in October 1870, by draining the swamp below the embankment, followed by the excavation of the puddle trench. It was determined to sink the trench at a distance of 45 feet 6 inches from, and nearly parallel to, the old face wall; by so doing the trench was carried through nearly the whole depth of the embankment, and, for the most part, a good foundation of well-consolidated material was secured for the front, and the greater part of the back slope. The removal of the necessary material, which was of inferior quality, allowed of its place being filled up on each side of the puddle wall with selected earth. This trench (Plate 1, Fig. 9) had side slopes varying from ¼ to ½ to 1, up which steps were cut, by which the coolies carried basket-loads of earth, either to form the slope of 2 to 1 in front of the face wall, or the base of the outer slope where it extended beyond the embankment. While the excavation was in progress the water in the old reservoir stood from 15 feet to 20 feet above the deeper portions of the excavation, the leakage being pumped out by a portable engine and centrifugal pump. In cutting the trench, as the rock was approached, several springs of considerable volume were intercepted at, and a little to the north, of the two square depressions in the floor of the puddle trench (Plate 1, Fig. 2), 1,000 feet from the south end of the embankment. The water in these springs came from the outer side of the trench, and probably was the subsoil drainage of high land to the south-east of the southern end of the embankment; for, when this part of the trench was filled with puddle, the springs below the embankment increased, although it was towards the end of the hot season. The trench was 1,033 yards in length, of an average depth of 25 feet, and an extreme depth of 36 feet near the old sluice. The bottom width in the rock was 5 feet, the top varied from 20 feet to 49 feet. The quantity of material excavated was, in the old embankment, 965,718 cubic feet; in the ground below the old embankment and above the rock 243,788 cubic feet, and in the rock itself 58,970 cubic feet, making a total of 1,268,476 cubic feet, or about 47,000 cubic yards. The cost, including blasting, pumping, and preliminary drainage, was 23,681 rupees, or at the rate of a fraction over 1*s*. per cubic yard.

The puddle wall, filling the trench, and forming the centre of the embankment, was constructed with clay, spread in even layers not exceeding 8 inches in thickness, soaked in water during the night, and worked up in the early part of the following day.

There being no good clay procurable in the immediate neighbourhood of the works, it was brought from a distance of 3 miles in bullock carts. The width of the puddle wall (Plate 1, Fig. 9) at the top is 5 feet, with a batter on each side of 1 inch per foot; this makes the thickness at the ground level about 10 feet. It decreases from that width down to 5 feet in the rock at the bottom of the trench. The consumption of puddle was 900,000 cubic feet, or 33,300 cubic yards, and, as it cost 66,586 rupees, the work was executed at a rate of 4*s.* per cubic yard, including digging, carting, and working. The earth from the puddle trench was placed in front of the face wall at a slope of 2 to 1 (Plate 1, Fig. 9). The berm on the top of the old embankment, to prevent the face wall becoming surcharged, is 9 feet 6 inches wide, and is raised 2 feet 4 inches above the old wall. The top of the ancient embankment has been carefully trenched longitudinally to insure a junction between the old and the new work. The general inclination of the inner slope is 2½ to 1, that of the outer slope being 2 to 1. The top of the embankment is 6 feet above the sill of the waste weir, and has an extreme width of 7 feet 6 inches, being finished off with curbs of rough stone laid dry. Black cotton soil was placed on each side of the puddle wall in the trench, and was raised above the level of the old bank at a slope of 1 to 1, the outer portion of the embankment being the harder and less retentive material. The earth was deposited by coolies from baskets in layers about 1 foot thick, each layer being watered, trodden, and punned, before the next was laid on. The inner slope is pitched with hard stone 1 foot thick; the outer slope is turfed, the berm, or road, at its foot being composed of stones, trap rock, and gravel.

The total cost of thus raising the embankment was 42,774 rupees; there are about 2,900,000 cubic feet, or 107,407 cubic yards of earthwork, which cost on an average 5½ pence per cubic yard. The rates for the pitching varied from 5*s.* to 10*s.* per 100 superficial feet, and for the turfing 2*s.* per 100 superficial feet.

The reservoir was full in October, 1872, nearly so in 1873, and 1·3 foot of water flowed over the waste weir in August 1874. Three monsoon seasons have passed, and, with the exception of a slip of earth from the back slope, in September 1872, which was soon repaired, all has gone well. This slip may be attributed to the new earthwork parting from the old slope, possibly caused by the boggy ground at the toe of the slope.

It was not considered prudent to break through or interfere with the continuity of the face wall, or to run the risk of laying the discharge pipe under the full height of the embankment; and as a tunnel round the end would have been expensive, owing to the flat slopes of the valley (Plate 1, Fig. 10), it was at last determined to bring the pipe over the top of the face wall, using the masonry in the old sluice as a partial support.

The outlet finally adopted was a straining and regulating tower (Plate 2, Figs. 1, 2, and 3), about 30 feet from the face of the sluice inside the reservoir. The excavation for the tower was made within an earthen embankment run out from the old face wall, the inner toe being supported by piles and planking. It was carried down to the rock 12 feet below the former bed of the reservoir, and 18 feet below the water level; and when the masonry rose above the top the temporary earthen dam was removed. The internal dimensions of the tower are 15 feet by 6 feet; up to the former ground level it is of basalt rubble, the space between the walls being filled with concrete; above that level it is of sandstone ashlar, with the upper part and the arching set in Portland cement. The face most distant from the embankment (Plate 2, Fig. 1) is pierced by three openings 2 feet square fitted with cast-iron sluice doors, moved by cross-heads and screws, placed in the three pillars resting on a cast-iron girder at the top of the tower; by these sluices the water can be drawn from near the surface.

Sliding in three grooves in the inside of the tower are six straining frames, carrying copper-wire gauze strainers of thirty meshes to the inch; and outside the three square sluices the water passes through a $\frac{5}{8}$-inch wire netting supported on iron cross-bars. The upper part of this tower is partly arched over so as to give an area of 286 superficial feet for convenience in lifting the strainers working the sluices, &c. The openings between the arching are covered with removable planking.

A foot bridge of wrought iron, 81 feet long and 3 feet 6 inches deep, supported in the centre by an ashlar masonry pier, extends from the top of the embankment to the tower.

The syphon commences at the bottom of the tower. It is 2 feet in diameter, 184 feet long, and from 1 inch to $1\frac{1}{2}$ inch in thickness. The lip is 31 feet from the top of the coping, and the inner end is commanded by a sluice valve, the spindle of which is prolonged upwards and terminates in a cast-iron pillar on the top of the tower, from which it can be worked. Between the straining tower and the masonry of the old sluice the pipe is carried on a semi-arch of rubble masonry, abutting at one end against the rock and the foundation of the tower, and at the

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other end against the old sluice into which it is built. The width of this arch is 4 feet, and its upper surface is in steps faced with sandstone ashlar; on these steps ashlar blocks, 1 foot wide, carry the syphon, which is also inclosed in rubble masonry.

The wells (A and B) of the old sluice having been filled with concrete, and the openings in them built up, the pipe is borne partly on sandstone blocks, and partly on concrete and the masonry of the old sluice. Walls of rubble masonry are so built across the pipe as to allow of the flanged joints being surrounded with puddle, and the remainder of the pipe with concrete.

The pipe passes through an arched opening in the pier which supports the foot bridge, and where it crosses the puddle trench it rests on a masonry pillar, which also carries the end of the foot bridge; on the outside of the puddle wall it is supported on the foundations of the charging well. Between the well, B, of the old sluice and the support pillar of the bridge, the pipe is carried over the opening of 16 feet on sandstone blocks resting on two wrought-iron rolled beams 1 foot deep, rivetted together. Between the pillar and the charging well the large pipe, 14 feet in length, rests, for the distance of 10 feet spanning the main puddle trench, on stone blocks supported on two wrought-iron girders 8 inches deep. Down the back slope of the embankment the syphon is sustained on a semi-arch of concrete 5 feet in width, on the steps formed in the top of which are sandstone blocks, 1 foot wide, which support the pipe. Cross walls are also provided, with puddle round the joints and concrete covering the remainder of the pipe. At its lower end the pipe is curved vertically upwards and covered with a semispherical cover, carrying one of Bateman and Moore's 8-inch air valves—an arrangement to prevent air from the main pipe entering the syphon and discharging it. The outer end of the syphon terminates in a valve house, in which are inclosed the air valve and two valves, 15 inches in diameter, placed on a branch which projects at right angles from the syphon. One of these valves governs the supply to the city, the other is arranged for scouring out the straining tower and syphon, or for giving off surplus storage water for irrigation.

The crest of the syphon is in the charging well, and at that point the pipe is provided with a branch 4 inches in diameter. This branch is closed by two valves with a gauge glass between them; the upper end of the branch having a funnel mouthpiece for charging the syphon, when the terminal valves are closed.

The flanged joints of the pipe (Plate 2, Figs. 4 and 5) are secured by eight bolts. A conical projection of 2 inches, carrying an india-rubber rope washer, fits against a recessed shoulder in the corresponding opposite pipe; the faces of the flanges are also provided with flat india-rubber washers $\frac{1}{8}$ inch thick, and a turned projection and recess in the corresponding flanges. The joints were made good with red-lead and oil; and the thickness of the india-rubber washer between the flanges outside, and any small openings round the bolt holes, as well as inside the pipe at the point of junction, were caulked with iron rust joint cement, after which the whole of the outside of the joint was covered with Portland cement before it was surrounded with the puddle.

Where the pipe crosses the puddle in the trench, great care was taken to bed it firmly. The puddle was allowed to settle after it had been worked up during one whole monsoon and cold season, say for eight months; it was then consolidated by repeated blows from a monkey weighing 10 cwt., and beds were cut in it to receive the girders. These were filled with well-rammed puddle to prevent water passing along them, and their ends were set in neatly-fitting sandstone chairs run in with Portland cement. For a few feet above, and on each side of the pipe, the puddle was worked up softer than usual to prevent its clinging to the pipe.

The lift of the syphon, from the sill of the lowest sluice in the straining tower to its crest in the charging well, is 14·55 feet; and as the water in the reservoir will never be drawn lower than 5 feet above that level, the syphon will not be required to lift more than 9·55 feet, and at this level the valves in the valve house would be 5·2 feet under the surface of the water.

The total cost of the outlet, including the straining tower, foot bridge, charging well, and valve house, was 28,935 rupees. The rates were, for ashlar from 1*s.* to 2*s.* per cubic foot, for basalt rubble from 10*s.* to 16*s.* per cubic yard, and for concrete 8*s.* per cubic yard. The cast-iron sluices, valves, &c., were obtained under a lump contract.

The new waste weir (Plate 2, Figs. 6 and 7) consists of a curved wall, 200 feet long by 3 feet thick, capped with ashlar, protected on each side by training walls 120 feet in length. The water flows over the weir into a rock cutting, which for the first 150 feet has a fall of 1 in 45, converging from 150 feet to 60 feet in width; from thence the inclination increases up to 1 in 40. The sides of this cutting being rocky, little masonry was required, and the cost was only 8,214 rupees.

The main and city distribution pipes work under an average head, when the reservoir stands at low water, of from 30 feet to 60 feet. As there are few high houses in Nágpúr, this pressure is considered sufficient, and all the water is supplied on the ground level. The service is almost entirely a public one, the water being given off from self-closing standards, at intervals of about 100 yards along the streets, only a few houses being as yet supplied with private taps or cisterns. Fire-cock air valves are also placed at every 100 yards apart.

The cast-iron piping was supplied by Messrs. R. Maclaren and Co., of Glasgow, at rates of 70 rupees 12 annas to 72 rupees 8 annas per ton delivered in Bombay; but the railway carriage raised the cost to an average of nearly 117 rupees delivered in Nágpúr. The contract for the pipes was signed in Nágpúr on the 1st of February, 1871, and the first consignment was received on the 15th of the following July, it having been shipped *viâ* the Cape of Good Hope.

The total cost of the works, including engineering expenses, a bungalow at the reservoir for the engineer in charge, and a road 2½ miles in length to Nágpúr, was 395,320 rupees, or say £40,000, representing a rate of 9*s.* 5*d.* per head, or £31,500 per million gallons supplied per day. This does not, however, give a perfectly correct idea of the cost, as a portion of the embankment previously existed, and about 10,000 yards of additional distribution pipes are still required to bring the supply up to a European standard.

The work was executed under the Author's supervision, partly by petty contractors, partly by day labourers; many prisoners were also employed, the jail authorities being paid for their labour by piece-work, at the rates accepted by the petty contractors.

THE INTENSITY OF RAINFALL AND THE PROPORTION FLOWING FROM THE GROUND AS OBSERVED AT NÁGPÚR.

Although the general fluctuation of rainfall in India is similar to that in other parts of the world, yet it has certain well-marked peculiarities. The first of these is, that the greater part of the annual rainfall is confined to a few months during the south-west or north-east monsoons; secondly, that the greater part of the year is almost rainless, and thirdly, that during the wet months the rainfall is much more intense than in temperate countries. To take two well-known cases on record, a fall of 23½ inches in twenty-four hours has been measured at Madras, and on another occasion a depth of 14 inches in twenty-four hours was gauged at Bombay.

In the Appendix, Table II., page 25, gives the details of certain extraordinary showers which came under the Author's observation at Nágpúr during the monsoon of 1872. The showers range from 0·5 inch in depth up to 3·92 inches, and the rate of fall or intensity from 0·163 inch to 4·733 inches per hour. The rainfall, noted in Table II., is the average of three gauges placed within the catchment area of the Ambájharí reservoir. The quantity of water discharged from the area of 4,224 acres was measured by noting the amount and the time of rise of the water in the reservoir. These showers produced a flow varying from almost nothing, in the case of the shower of 2·24 inches in one hour and twenty minutes on the 18th of June, up to a discharge of 33,160,380 cubic feet due to a fall of 2·2 inches in one hour and twenty minutes on the 16th of September. These facts prove to what an extreme state of dryness the soil in India is reduced at the end of the hot season, and how saturated it becomes after heavy rain later on in the monsoon. In the last column of Table II. is given the proportion of the rainfall of the various showers which flowed from the ground in the times noted in column 6. From this it will be seen that, of the 2·2 inches on the 16th of September, 98 per cent. entered the reservoir within two hours and fifty minutes.

The consideration of the above remarks naturally leads to the question, What percentage of the total annual rainfall flows from the ground and can be impounded? Almost every drainage area has, in this respect, peculiarities. proper to itself, but the Author will confine his remarks to the facts observed at Nágpúr; and as there are two peculiarities which he thinks will be found common to most cases in India, he wishes first to invite attention to them.

It will be noticed in Table I. that the average annual rainfall at Nágpúr is 40·73 inches, of which 37·52 inches fall in the monsoon, and 3·21 inches in the dry season. But no dependence can be placed upon this latter quantity as a means of water supply, for careful observations have failed to detect any part as flowing from the ground into the reservoir. And, secondly, to such a state of dryness is the ground reduced in the commencement of June, that a large portion of the first showers of the monsoon are either absorbed or evaporated, and but a small portion flows from the ground. The consequence is that the records of the discharge of the drainage area are confined to about four months, and when plotted form a curve, owing to the proportion which is discharged, commencing at zero at the beginning of the monsoon and gradually increasing as the rains continue. These facts render the study of the subject much more simple for Nágpúr than for places in England; because the observations of each year commence under the same circumstances, and as it were from a common datum or point of departure.

The observations on the discharge of the Ambájharí drainage area (Plate 3) extend over the monsoon months of the years 1869 and 1872. Commencing with 1869, from the 17th of June to the 31st of July a depth of 12·76 inches of rain was gauged; the quantity of water that flowed from the ground, being about 19,600,000 cubic feet, showed that only 1·25 inch had passed off, which gives about 90 per cent. as either evaporated or absorbed. The rainfall for August was 9·61 inches, of which the proportion discharged was 35 per cent., and for September it was 7·41 inches, of which 44 per cent. flowed from the ground. Up to the end of each month the total effects were—June and July as above quoted; June, July, and August, 22·37 inches of rain, and a discharge of 20 per cent.; up to the end of September, 29·79 inches of rain, and a discharge of 26·8 per cent. In 1872 the proportions were, for 6·77 inches in June the amount discharged was 4·7 per cent.; for 12·70 inches in July, 22·7 per cent.; for 11·82 inches in August, 55·8 per cent.; for 7·99 inches in September, 74·4 per cent.; and after an interval of dry weather, for the 4·37 inches in October, 39·4 per cent.

The result was that the total discharge increased as follows: for June 4·7 per cent.; up to the end of July 16 per cent.; up to the end of August 31 per cent.; up to the end of September 40 per cent.; and at the end of October it still remained at 40 per cent. In Plate 3 the horizontal measurements represent inches of rainfall, and the vertical ones the percentage which flowed from the ground into the reservoir. Hence it can be ascertained what the discharge of the drainage area will probably be for different depths of rainfall, as the proportion absorbed will depend, all other circumstances being equal, on the depth of the rainfall. Thus, for an average season's fall, or 37·52 inches, 38 per cent. may be expected, or 14·25 inches, equal to 217,120,000 cubic feet. In a season the fall of which was that of the average of the three driest consecutive years, or 30 inches, the discharge would be about 28 per cent., or say 8·4 inches. This would yield 128,000,000 cubic feet, and in a year such as 1868, the driest on record, when the amount was 19·28 inches, about 15·5 per cent., or 3 inches would flow from the ground and yield only 46,000,000 cubic feet. These calculations deal only with the flow from the drainage area. But the actual quantity of water that can each year, without fail, be utilised, depends not only upon the fluctuation of the rainfall, and the proportion which flows off the ground, but also upon the capacity of the reservoir to store and modify the fluctuations.

To render this matter as clear as possible, the Author has worked out, from the diagrams (Plate 3) and a revised twenty-years' record of rainfall, Table III. (page 26), which shows what proportion of each year's fall would in all probability have flowed off the ground, and also the actual depth in inches and quantity in cubic feet discharged in former years. Taking this as a basis of calculation, nine different cases have been assumed of reservoirs with varying capacities, affording different amounts of annual supply. Each case has been carefully tabulated on the common system of supply and demand, to indicate what amounts of the water flowing off the drainage area could be used, or how much would be wasted; and also what would be the minimum storage in the reservoir at any time during the twenty years under review. The results of these calculations are given in Table IV. Tables III. and IV. show that the proportions between the average, maximum, minimum, and the three consecutive driest years' rainfall do not correspond with the equivalent proportions in the yield of the drainage area. Thus the minimum rainfall is 52 per cent. of the average, while the minimum yield of the drainage area is only 23 per cent. of its average yield. In the same way the yield of 37 inches, an average year's fall, would be 38 per cent., and give 215,280,000 cubic feet; but the average yield of the drainage area is only 204,520,000 cubic feet. This matter requires attention, as the working out of Table IV. will show, where the storage and the supply are given in terms both of the rainfall and of the yield of the drainage area.

It will be seen from Table IV. that the present reservoir, with a capacity of 240,000,000 cubic feet, can store 117 per cent. of the average yield, or 106 per cent. of the average rainfall; and that it can supply from 120,000,000 to 140,000,000 cubic feet per annum, which represents from 58 per cent. to 68 per cent. of the average yield, and from 77 per cent. to 82 per cent. of the rainfall. The average annual waste is from 84,000,000 to 62,000,000 cubic feet, and the smallest storage in any year is equal to from fifteen up to one hundred and forty days' supply, according to the quantity used. To afford a supply of 180,000,000 cubic feet, or 88 per cent. of the average yield, and 95 per cent. of the average rainfall, the case marked No. 9 shows that the reservoir must store 340,000,000 cubic feet, a quantity equal to 150 per cent. of the average rainfall and to 166 per cent. of the average yield of the drainage area. The number of days' supply which it is necessary to store varies from six hundred and fifty-six up to seven hundred and thirty among the cases cited, but for perfect safety the reservoir should contain two years' supply.

The quality of the water discharged by the drainage area is shown by the following analysis, made by the Chemical Examiner to the Government of Bengal in 1865:—

In 70,000 *Grains*:—

	Grs.
Solid residue	6·9
Organic Matter	1·8
Silica	0·6
Carbonate of Lime	1·41
Carbonate of Magnesia	1·59
Chloride of Sodium	0·42
Sulphate of Soda	a trace
Carbonate of Soda	1·08

That sample was taken from the old tank, but as the area and the depth and capacity of the reservoir are now largely increased, the probability is that the water is purer.

EVAPORATION.

In India a most important matter for consideration is the amount of evaporation. Not only is a large portion of the actual rainfall thereby lost before it flows off the ground during the monsoon months, but a large quantity is evaporated from the surface of the reservoir during the long, hot, and dry season, extending from October to June. During this time no portion of the average rainfall of 3·21 inches flows off the ground, although the actual surface of the reservoir is raised by the rain which falls upon it.

To determine the quantity evaporated from the surface is a matter of difficulty. But the Author during the dry season of 1872–73 attempted, by carefully observing the level of the water in the reservoir, and by comparing the result with the existing meteorological circumstances, to estimate the amount. The result is given in Table V. It will be observed from column 2, that the total loss of water from all causes during the dry season of two hundred and forty-two days, extending from the 10th of October, 1872, to the 9th of June, 1873, was a depth of 7 feet, or at the average rate of 0·0289 foot per day. This at once disposes of the large amounts of 8 feet, and even 10 feet, sometimes asserted to be the evaporation in India during the dry season. From columns 5 and 8 it will be seen that this diminution varied from 1 foot in twenty-two days, or 0·0454 foot per day, to 1 foot in forty-two days, or 0·0238 foot per day, and that, commencing with a diminution of 0·0286 foot in October and November, it fell to 0·0238 foot in December and February, rising to 0·0454 foot in April and May, and finally declining to 0·0303 foot during May and June. The Author believes that this wave-like rise and fall in the total loss to the reservoir is due to the increase and decrease of the evaporation, and this is confirmed by the meteorological observations in column 15. These show that when the comparative humidity of the air was least the diminution was greatest, as during the period from the 15th of April to the 7th of May, and that when the air was most humid, during December and February, the diminution was least. It will be noticed that the period of maximum loss occurred when the comparative humidity was the least recorded, viz., 0·37. Columns 12, 13, and 14 prove that the greatest loss of water does not occur when the temperature of the air is greatest; for both the maximum and the mean temperatures were less during April and May, and the maximum evaporation in April, when the total loss varied from 0·0498 foot to 0·0454 foot per day, was less than during May and June, when the temperature was highest, and the loss was only 0·0303 foot per day. The temperature of the water at a depth of 5 feet below the surface generally agreed, within 1°, with the mean temperature of the air; thus in June it varied from 90° to 92°; and on the 24th of May, 1873, the temperature of the water flowing in the river Kanhan was 96° at 9 A.M.

It is believed that a near approximation to the quantity of water evaporated, out of the total daily loss shown in column 7, will be arrived at by deducting 200,000 cubic feet per day for the quantity used in the city, and for soakage through the ground on which the reservoir stands. This is the basis of calculation in the quantities and depths stated in columns 9 and 10, in which the amounts of evaporation vary from 163,357 cubic feet, and 0·0107 foot up to a maximum of 506,350 cubic feet, or 0·0357 foot per day. From the figures given in column 10 it is found that the evaporation amounted to 3·75 feet, but to this must be added 3 inches of rainfall, registered in various small showers from October to June; so that the total depth evaporated may be taken at 4 feet, which, distributed over the two hundred and forty-two days, gives an average of 0·0165 foot, or 0·198, say $\frac{1}{5}$ inch per day.

The importance of the question of evaporation to the reservoir at Nágpúr may be inferred from columns 3 and 6. The total loss of water during the season amounted to 104,180,000 cubic feet, out of which, by the above calculation, 55,781,000 cubic feet were evaporated, leaving only 48,399,000 cubic feet as used or absorbed; in other words, of the total quantity lost to the reservoir during the dry season the proportion evaporated was 54 per cent.

FLUCTUATION OF RAINFALL IN INDIA AND IN OTHER PLACES.

In designing reservoirs, not only should the amount of annual rainfall be considered, but the fluctuations to which it is liable. In England the question has long received careful study, and certain rough approximate rules have been arrived at, so that an idea can be formed of the variations to which the mean annual quantity is subject. In designing these works, however, the Author had some difficulty in deciding on this matter, as it was his first work in India, and as it was said that rules good for England were inapplicable to the tropics. Accordingly, the Author was led to analyse the records of rainfall at Calcutta, Madras, Bombay and Nágpúr, at the same time comparing them with the records kept for longer or shorter periods in other places in different parts of the world. The results, with subsequent additions, are epitomised in Table VI. To arrive at a common standard of comparison, the mean annual amount of rain has been adopted, and in doing so care has been taken to admit no records which do not extend over at least nineteen years. In all cases this mean annual amount, varying as it does from 16·44 inches at Prague to 76·80 inches at Bombay, is taken as unity; and the proportions above or below are expressed as unity plus a decimal part, where it rises above the mean annual amount, or a decimal part of it where it falls below.

The points which have received attention are the percentages in the number of years whose rainfall is above or below the average; the average fall of all the years when the rainfall rises above the average, and when it is below it; the average rainfall of the three driest consecutive years; the maximum and minimum early rainfall, with the range or extreme difference; the number of periods of three consecutive years of rainfall below the average which may be expected from the records to occur in every hundred years; the greatest number of consecutive years in which the fall of rain is below the average; and, lastly, the average rainfall of the greatest number of consecutive years below the average.

By working out one case, the *modus operandi* will be understood, and an opinion can then be formed of the value to be attached to the Author's deductions. For this purpose Calcutta is selected. The average annual rainfall for thirty-seven years, from 1836 to 1872, is 66·75 inches. During this period there were sixteen years when the rainfall was above, and twenty-one years when it was below the average, giving percentages of 43 and 57 respectively. The average fall of rain in the sixteen wet years was 77·47 inches, which, expressed in terms of 66·75, the mean annual fall considered as unity, is 1·16. In the same way the average fall of rain in the twenty-one dry years is 58·6 inches, or 0·88 of the mean annual fall. The average fall of the three years 1836, 1837, and 1838, all of which were dry, was 47·33 inches, or 0·71 of 66·75 inches considered as unity. The wettest year on record was 1871, when the fall was 93·31 inches; and the driest 1837, when it was only 43·61 inches. These quantities, reduced to terms of the general mean average, give 1·4 and 0·65 respectively, and the difference between them is 0·75.

During these thirty-seven years, there were six periods of three consecutive years each when the average rainfall was below the mean, viz., 1836–38, 1839–41, 1843–45, 1851–53, 1856–58, and 1865–67; therefore, in the same proportion, 16·2 such periods may be anticipated in every hundred years. The rainfall of each of the six years, 1836–41, was below the general mean, and as the average of those six years was 54·44 inches, it is expressed as 0·83 of the general mean 66·75 inches.

Table VI., with its record of fourteen places situated in every quarter of the globe, the observations at which extend over periods varying from nineteen to sixty years, shows a similarity in the results obtained, notwithstanding the differences of climate, geographical position, and the varying amounts of the mean annual rainfall. A perfect agreement cannot be looked for, but the nature of the fluctuations is the same, and it may be expected that, as rainfall observations are extended, the difference will become better understood. In the majority of instances, the number of dry years exceeds the wet ones in the proportion of 54·2 to 45·8, the greatest divergence being 7·8 per cent., in the case of New Bedford, U.S. With regard to the average fall of all the years when the rain is in excess, the accordance is very striking, the average being 1·19, and the greatest difference, in the case of Madras, only amounting to 9 per cent. Again, the proportion of the fall of the years when the amount is scanty is 0·83, or within 6 per cent. of Madras and Hobart Town, the two extreme results. For the period of the three consecutive driest years, the average of all the observations is 0·76, and the greatest divergence from this is in the case of Madras, where it amounts to 11 per cent. Taking into consideration the maximum fall, the average of all the cases being 1·52, the greatest difference is 30 per cent. at Madras. In like manner the average of the minimum fall is 0·59; the greatest departure from which is again at Madras, where it is 21 per cent. Thus, as the average range is 0·93, it differs from Madras by 51 per cent; but in the case of maximum and minimum falls, it must be remembered that the records are for single years of the greatest known extremes, and a perfect accordance is not to be anticipated. The general average of the periods of three consecutive years' rain below the mean, which may occur in every hundred years, is 20·3, the greatest difference being at Calcutta, where it is 16·2.

In the various cases recorded, periods of from nine consecutive years downwards have occurred, in all of which the fall of rain has been below the average. This is a matter which does not allow of an average being struck; but it is a guide to what may occur. The mean fall of the greatest number of consecutive dry years agrees almost exactly with that of all the years below the average, and the general average of all the cases in the last column is 0·82, within 1 per cent. of the general mean of all the years of minimum fall. The Author does not wish, from the foregoing remarks, to be regarded as advocating a strict rule to be applied in all cases, or as urging new views on the subject, but merely as directing attention to certain general and broadly-marked features, common to all parts of the world; and particularly as pointing out their applicability to India, notwithstanding the other peculiarities of the rainfall in that country.[1]

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[1] No inquiry likely to throw light on the investigation of this important subject should, however, be neglected. The sun, as the great source of light and heat, is the principal agent in producing rain. Were this not capable of proof on other grounds, the results in Table VI. would lead the mind to look for a single force continually acting on all parts of the globe, to produce the general uniformity there observed.

During the past few years it has been suggested that the periods of fluctuation of the spots on the sun's disc bear a relation to the fluctuations of rainfall, similar to those which have been demonstrated in the case of terrestrial magnetism. To test the truth of this statement, a comparison was instituted between the fluctuations in the rainfall at the fourteen places referred to in Table VI., and the solar spot periods from Schawbe's observations, as given by Proctor, from 1826 to 1869. The latter included four periods of maximum spot frequency, viz., 1828–30, 1836–38, 1847–49, and 1859–61; and four periods during which the sun's disc was almost free from spots, viz., 1832–34, 1842–44, 1854–56, and 1866 and 1867. No satisfactory result or accurate deductions can be drawn from this test; but during

CONCLUDING REMARKS.

In conclusion the Author would suggest to the younger members of the profession who wish to enter the Public Service in

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the period when the spots are about a maximum, great fluctuations in rainfall occur, principally, but not without many exceptions, in the direction of an excess above the mean annual fall; and during the time when the sun is least obscured, the fluctuations approach near to the average or fall below it. Moreover, a longer period elapses during which the spots are fewer than when the obscuration is great. The proportion is as 38 to 62; which corresponds, as will be seen in Table VI., to within 8 per cent. of the average of the percentages in the numbers of the years which rise above or fall below the average, and is in agreement with the cases of Barbadoes and New Bedford. Taking now these proportions of the spot curve, 38 and 62, and comparing them with the average amount of the fall of years above and below the mean, which is shown in Table VI. to be 1·19 and 0·83, and which are to each other as 59 to 41, they are almost complements of each other; thus 38, the proportion of the spot curve corresponding to the maximum, added to 59, the proportion of the rainfall in years above the average, is equal to 97; while 62, the proportion of the spot curve corresponding to a minimum, added to 41, the proportion of the rainfall in years below the average, is equal to 103. From Table VI. it appears that the average number of periods of three consecutive dry years per hundred years is 20·3; that is, at distances apart of 4·92 years, agreeing, within 8 per cent., with the half of the ten-year period, which, according to Schawbe's observations from 1826–69, separates the fluctuations of the solar spots. Table VII. is a statement of the rainfall in inches, at the fourteen places in Table VI., during the three-year maximum and minimum sun-spot periods from 1828–67. If the sun-spot periods do affect directly the fluctuation of rainfall, this Table should show an increase and decrease in the total amounts of rainfall during the three-year maximum and minimum sun-spot periods; but no such wave-like rise and fall in the amount of rain is found, for any long period, through any one series, excepting in the case of Prague; all the other cases, with slight exception, being more or less confusing. Turning now from individual cases, to the consideration of the sum of the results of Calcutta, Bombay, Madras, Greenwich, and Prague, extending over the six periods from 1836–67, as given in Table VIII., the average total fall is 689·23 inches; a comparison of this amount with the actual total falls does not show an approach to a satisfactory result, except in the four latter periods, extending from 1847–67. But it is only in the case of the seven places in Table IX. which extend over the four periods from 1847–67, or that of the nine places in Table X., extending only over the three periods from 1854–67, that there is any approach to a wave-like rise and fall in the amount of rain, corresponding with the maximum and minimum sun-spot periods. In the present state of knowledge of the subject, the connection between sun-spot periods and the amount of rainfall is not capable of demonstration; and even assuming the results of the short periods dealt with in Tables IX. and X., and the last four periods in Table VIII., to represent the amount of the fluctuation due to the solar-spot periods, yet it is so small (the extreme average fluctuation amounting to only about 13 per cent.), that, when compared with the other larger and well-established fluctuations shown in Table VI., it may for professional purposes

India, that in a project, such as this, they may be called on not only to prepare the plans, sections, working drawings, and specifications, but also to study great natural laws in the general design; and during the construction of the works they will not have the assistance of the trained staff of a large contractor, but may have to arrange, prepare, and work all the necessary plant and organise the workpeople. A knowledge of accounts is a most useful acquisition; in India this is almost indispensable, as nearly all Government engineers have to keep their own accounts and receive and disburse the money expended on the works. But the most important matter for special attention in carrying on their duties will be, the exercise of careful personal supervision of every detail of construction, and of all the materials with which they have to deal: for the subordinate inspection at their disposal is not of the highest class, nor is it implicitly to be relied upon.

The communication is accompanied by a series of drawings and diagrams, from which Plates 1 to 3 have been compiled.

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be neglected. Possibly the mode of investigation adopted by the Author may not be the correct one: it may be that the effect produced by the sun's action is not contemporaneous on all parts of the globe; yet it is difficult after an inspection of Table VI., and considering the vast forces at work, to think that such is the case. The Author does not feel justified, from the result of the above investigation, and with the materials at present at his disposal, in drawing other or more exact deductions; but he hopes the subject will receive the attention it merits from those better able to deal with it than himself. He is, however, of opinion that attention should in all cases be directed to general facts, and the mind be withdrawn from too close a study of variations within limited areas, as he conceives it will be easier to work from well-ascertained principles, common to the whole world, down to the details of particular countries, rather than the reverse.

UNIVERSITY CALIFORNIA

[APPENDIX.

APPENDIX.

TABLE I.—GIVING the MONTHLY, MONSOON, and ANNUAL RAINFALL at NÁGPÚR for the NINETEEN YEARS 1854–5 to 1871–3.[1]

Months.	1854–5.	1855–6.	1856–7.	1857–8.	1858–9.	1859–60.	1860–1.	1861–2.	1862–3.	1863–4.	1864–5.	1865–6.	1866–7.	1867–8.	1868–9.	1869–70.	1870–1.	1871–2.	1872–3.	Averages.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches	inches.	inches	inches.	inches.	inches.	inches.	inches.	inches.
June . .	6·43	5·40	7·20	10·52	3·85	6·59	4·76	13·84	10·48	10·44	7·34	10·60	6·20	14·50	4·00	4·12	9·49	12·80	4·01	8·03
July . .	24·81	7·50	24·00	4·46	11·96	6·36	15·23	17·16	1·57	15·66	9·10	13·46	10·10	12·70	8·87	8·62	18·98	17·15	7·44	12·74
August .	4·44	3·60	10·02	8·56	5·88	14·94	8·72	8·63	11·02	4·24	8·52	8·60	14·42	10·70	4·66	9·61	1·78	2·04	9·35	7·88
September	9·57	4·45	2·79	7·17	9·60	1·51	15·76	1·26	6·66	6·51	4·00	3·70	8·89	13·28	1·67	7·30	5·00	12·86	14·80	7·36
October .	3·15	3·09	0·32	2·75	0·58	0·08	0·03	..	3·56	0·61	..	1·80	1·40	2·54	0·08	2·46	2·09	..	4·22	1·51
Totals of the 5 monsoon months	48·40	24·04	44·33	33·46	31·87	29·48	44·50	40·89	43·29	37·46	28·96	38·16	41·01	53·72	19·28	32·11	37·34	44·85	39·82	37·52
November	..	..	..	..	..	..	..	..	1·07	..	0·97	0·50	..	..	..	..	0·59	..	..	0·16
December	..	..	..	..	..	0·71	..	..	0·31	..	..	..	0·20	0·05	..	0·39	..	0·20	0·05	0·10
January .	0·98	..	0·14	..	..	..	3·11	0·12	0·12	2·04	..	..	..	4·84	..	2·14	0·17	..	..	0·72
February	0·45	..	0·06	2·07	..	0·41	..	..	..	..	..	1·90	..	..	..	..	0·20	..	1·02	0·32
March .	0·52	..	0·04	0·41	..	0·05	0·54	..	1·59	..	3·60	..	0·34	0·72	0·68	0·98	..	0·06	0·70	0·54
April . .	0·11	..	0·62	..	3·93	..	..	0·05	..	0·74	1·30	..	2·60	..	0·20	0·57	..	1·01	0·35	0·60
May . .	..	2·03	1·91	0·84	0·28	0·15	1·35	0·98	0·52	1·95	1·00	..	1·04	0·65	..	0·01	1·33	..	0·58	0·77
Totals of the 7 dry months	2·06	2·03	2·77	3·32	4·21	1·32	5·00	1·15	3·61	4·73	6·87	2·40	4·18	6·26	0·88	4·09	2·29	1·27	2·70	3·21
Annual totals	50·46	26·07	47·10	36·78	36·08	30·80	49·50	42·04	46·90	42·19	35·83	40·56	45·19	59·98	20·16	36·20	39·63	46·12	42·52	40·73

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[1] From 1854 to 1865 the observations were made by Lieut. Duncan at the Arsenal at Nágpúr, and from 1866–73 from figures furnished by the Sanitary Commissioner of Nágpúr.

TABLE II.—TABLE of EXTRAORDINARY SHOWERS at NÁGPÚR DURING the MONSOON of 1872.
Drainage Area, 4,224 Acres.

Dates. 1872.	Rainfall.				Rise of Water in the Reservoir, &c.						
	Amount.	Duration.		Rate of Fall per Hour.	Rise of Water in Reservoir.	Duration.		Total Quantity.	Rate of Flow per Minute.	Rate of Flow per Minute per Square Mile of Drainage Area.	Proportions of Rain flowing from the whole Drainage Area.
1.	2.	3.		4.	5.	6.		7.	8.	9.	10.
	inches.	hours.	mins.	inches.	feet.	hours.	mins.	cubic feet.	cubic feet.	cubic feet.	
18th June	2·24	1	20	1·684	unimportant.						
3rd July	3·92	24	..	0·163	1·50	24	..	9,242,400	6,420	973	0·160
10th July	0·71	..	20	2·131	0·32	3	..	2,197,216	12,207	1,849	0·204
12th July	1·26	..	30	2·520	1·00	3	..	7,571,800	42,066	6,374	0·392
9th August . . .	0·97	1	30	0·646	0·10	2	..	965,010	8,041	1,218	0·065
10th August . . .	3·50	1	45	2·000	3·15	3	..	32,565,960	180,922	27,412	0·607
24th August . . .	1·00	..	40	1·515	0·60	3	..	7,803,300	43,352	6,568	0·510
7th September. . .	0·60	1	..	0·600	0·60	5	30	8,586,000	26,018	3,942	0·940
16th September . .	0·50	..	30	1·000	0·40	6	..	5,877,600	16,326	2,474	0·760
	2·20	1	20	1·650	2·20	2	50	33,160,380	195,061	29,555	0·983
6th October . . .	0·50	..	20	1·500	1·34	3	..	21,509,520	175,053	26,371	0·346
	3·55	..	45	4·733							

TABLE III.—GIVING PROBABLE DISCHARGE of WATER from the DRAINAGE AREA of 4,224 acres, as deduced from the diagrams (Plate 3.), and the revised RAINFALL RECORD for each YEAR from 1854–5 to 1872–3.

Date.	Monsoon Rainfall.	Proportion Flowing from Ground.	Depth Flowing from Ground.	Yield of the Drainage Area.
	inches.		inches.	cubic feet.
1854	48·40	0·400	19·36	296,240,000
1855	24·04	0·215	5·17	79,120,000
1856	44·33	0·400	17·73	272,320,000
1857	33·46	0·345	11·54	176,640,000
1858	31·87	0·315	10·04	154,560,000
1859	29·48	0·285	8·40	128,800,000
1860	44·50	0·400	17·80	272,320,000
1861	40·89	0·400	16·36	250,240,000
1862	43·26	0·400	17·30	264,960,000
1863	37·46	0·380	14·24	218,960,000
1864	28·96	0·280	8·11	125,120,000
1865	38·16	0·388	14·81	226,320,000
1866	41·01	0·400	16·40	252,080,000
1867	53·72	0·400	21·49	329,360,000
1868	19·28	0·155	3·00	46,000,000
1869	32·11	0·320	10·27	158,240,000
1870	37·34	0·380	14·19	217,120,000
1871	44·85	0·400	17·94	274,160,000
1872	43·65	0·400	17·46	266,800,000
1873	24·25	0·217	5·26	80,960,000
Average	37·00	..	13·343	204,516,000

NOTE.—The rainfall of the years 1872 and 1873 differs from that given in Table I., since in 1871 the rainfall has been gauged at Ambájharí, 3 miles from Nágpúr.

TABLE IV.—GIVING PROPORTIONS OF RESERVOIRS.—Drainage Area 4,224 Acres.

Rainfall.	Inches.	*Yield of Drainage Area.*	Million cubic feet.
Average	37 = 1·00	Average	204·52 = 1·00
Maximum	53·72 = 1·45	Maximum	329·36 = 1·59
Minimum	19·28 = 0·52	Minimum	46·00 = 0·23
Average of three consecutive driest years	29·57 = 0·80	Average of three consecutive driest years	140·44 = 0·69

Number of Case.	Details of the different Cases.				Storage in Reservoir.			Annual Supply.			Average Annual Waste.		Minimum Storage.	
	Storage of Reservoir.	Annual Supply, including Evaporation.	Average Annual Waste.	Minimum Storage.	In Terms of Average Yield.	In Terms of Average Rainfall.	In No. of Days' Supply.	In Terms of Average Yield.	In Terms of Average Rainfall.	In Terms of Total Storage.	In Terms of the Average Yield.	No. of Years during which the Reservoir would have Overflowed.	In Terms of Annual Supply.	In Days' Supply.
	million cubic feet.	million cubic feet.	million cubic feet.	million cubic feet.										
1	240	120	84·47	46	1·17	1·06	730	0·586	0·771	0·50	0·414	17	0·38	140
2	240	130	71·57	26	1·17	1·06	675	0·635	0·818	0·54	0·365	14	0·20	73
3	240	140	62·47	6	1·17	1·06	656	0·684	0·821	0·58	0·316	14	0·04	15
4	270	150	51·97	16	1·32	1·19	657	0·733	0·853	0·55	0·267	13	0·11	38
5	288	150	52·31	34	1·41	1·27	700	0·733	0·853	0·52	0·267	13	0·23	85
6	288	158	43·87	18	1·41	1·27	665	0·772	0·865	0·55	0·228	12	0·11	41
7	300	160	41·47	26	1·47	1·32	684	0·782	0·871	0·53	0·218	11	0·16	59
8	330	165	35·47	45·36	1·61	1·45	730	0·806	0·886	0·50	0·113	9	0·27	100
9	340	180	21·47	4·24	1·66	1·50	688	0·880	0·953	0·53	0·120	6	0·02	8

TABLE V.—RESULTS of OBSERVATIONS on the EVAPORATION from the AMBÁJHARÍ RESERVOIR DURING the DRY SEASON of 1872-73.

Date.	Facts or Data.				Total Loss to Reservoir.			Approximate Evaporation.		Meteorological Observations.					Date.
	Height of Water on Gauge.	Quantity of Water in the Reservoir.	Area of the Reservoir.	No. of Days to fall 1 foot.	Total quantity lost per foot of fall over mean area.	Total average quantity lost per day.	Total average fall per day.	Daily quantity evaporated if 200,000 cubic feet are drawn off.	Depth evaporated per day if 200,000 cubic feet are drawn off.	Average Barometer.	Temperature.			Humidity.	
											Average.		Mean.		
											Max.	Min.			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
	feet.	cubic feet.	square feet.		cubic feet.	cubic feet.	foot.	cubic feet.	foot.	inches.	°	°	°	satur. = 1·00.	
1872 10th Oct.	22	249,898,500	16,206,000												
				35	16,017,000	457,629	0·0286	257,629	0·0161	28,871	87·5	61·3	74·5	0·77	10th Oct. to 14th Nov.
14th Nov.	21	233,881,500	15,828,000												
				40	15,639,000	390,975	0·0250	190,975	0·0122	28,919	84·2	57·6	70·9	0·80	14th Nov. to 24th Dec.
24th Dec.	20	218,242,500	15,450,000												
				42	15,261,000	363,357	0·0238	163,357	0·0107	28,933	84·9	53·7	69·3	0·82	24th Dec. to 4th Feb.
1873 4th Feb.	19	202,981,500	15,072,000												
				40	14,883,000	372,075	0·0250	172,075	0·0115	28,859	92·3	62·0	77·2	0·63	4th Feb to 16th Mar.
16th Mar.	18	188,098,500	14,694,000												
				30	14,505,000	483,500	0·0333	283,500	0·0195	28,758	104·2	73·2	88·7	0·51	16th Mar. to 15th Apr.
15th Apr.	17	173,593,500	14,316,000												
				22	14,127,000	642,136	0·0454	442,136	0·0312	28,716	107·2	76·3	91·7	0·38	15th Apr. to 7th May.
7th May	16	159,466,500	13,938,000												
				33	13,749,000	416,636	0·0303	216,636	0·0157	28,620	105·7	79·5	92·6	0·63	7th May to 9th June.
9th June	15	145,717,500	13,560,000												
18th April 30th April	16·90 16·30	172,180,800 163,704,600	14,279,200 14,051,400	20	8,476,200	706,350	0·0498	506,350	0·0357	28,720	107·9	74·7	91·3	0·37	Maximum Observation.

TABLE VI.—GIVING the FLUCTUATIONS of the RAINFALL as OBSERVED at FOURTEEN STATIONS, the PERIODS of OBSERVATION EXTENDING from NINETEEN to SIXTY YEARS, the VARIATIONS BEING EXPRESSED in TERMS of the MEAN ANNUAL RAINFALL at EACH STATION.

Place of Observation.	Period of Observation.			Mean Annual Rainfall.	Per-centage of Years above the Average.	Per-centage of Years below the Average.	Average Fall of all the dry Years.	Average Fall of all the rainy Years.	Average Fall of the three driest consecutive Years.	Maximum Fall.	Minimum Fall.	Extreme Range.	Proportionate Number of Periods of 3 consecutive dry Years per 100 Years.	Greatest Number of consecutive dry Years.	Average fall of the greatest Number of consecutive dry Years.
	From	To	Years.	Inches.											
Calcutta[1] .	1836	1872	37	66·75	43	57	1·16	0·88	0·71	1·40	0·65	0·75	16·2	6	0·83
Bombay[2] .	1817	1872	56	76·80	45	55	1·20	0·84	0·73	1·59	0·44	1·15	17·8	5	0·84
Madras[3] . .	1813	1872	60	48·60	45	55	1·28	0·77	0·65	1·82	0·38	1·44	21·7	9	0·76
Nágpúr[4] . .	1854	1872	19	37·52	53	47	1·17	0·80	0·79	1·43	0·51	0·92	21·0	3	0·79
Mauritius[5] .	1853	1872	20	42·95	50	50	1·20	0·80	0·67	1·60	0·48	1·12	20·0	3	0·67
Barbadoes[6] .	1843	1863	21	56·07	38	62	1·21	0·87	0·84	1·35	0·76	0·59	19·0	4	0·87
Adelaide[7] .	1839	1860	22	21·80	41	59	1·20	0·85	0·80	1·40	0·68	0·72	22·7	5	0·84
Hobart Town[8]	1841	1870	30	22·71	53	47	1·19	0·77	0·78	1·79	0·59	1·20	16·6	3	0·78
Cape Town[9] .	1842	1872	31	24·21	45	55	1·17	0·86	0·78	1·52	0·77	0·75	19·3	5	0·82
New York[10] .	1836	1854	19	42·77	42	58	1·22	0·84	0·81	1·53	0·64	0·89	21·0	6	0·84
Rome[11] . .	1821	1860	40	30·18	50	50	1·20	0·80	0·73	1·55	0·43	1·12	25·0	6	0·81
Greenwich[12] .	1820	1872	53	25·04	45	55	1·17	0·85	0·81	1·45	0·67	0·78	22·6	5	0·81
New Bedford U.S.[13] . .	1814	1855	42	41·40	38	62	1·18	0·89	0·86	1·40	0·74	0·66	23·8	9	0·90
Prague[14] . .	1832	1870	39	16·44	54	46	1·14	0·83	0·74	1·44	0·58	0·86	17·9	4	0·95
General averages . .	..	..	..	..	45·8	54·2	1·19	0·83	0·76	1·52	0·59	0·93	20·3	..	0·82

[1] Observatory, published in Thacker's Bengal Directory for 1873. Checked by "Calcutta Gazette."

[2] At Byculla, 1817–32, G. J. Symons; 1832–73, "Bombay Calendar," 1873; checked by "Bombay Gazette."

[3] Madras Observatory, 1813–66, vol. v. Balfour's "Cyclopædia of India"; 1866–72, "Madras Gov. Gazette."

[4] Monsoon rainfall, 1854–65, at Nágpúr Arsenal, Lieut. Duncan; 1865–72, Nágpúr Sanitary Commissioner.

[5] Port Royal; monthly notices Met. Soc. of Mauritius.

[6] Halton St. Philip, "Met. Mag.," 1864.

[7] "Quarterly Journal Met. Soc."

[8] Results of Met. Obs. published at Hobart Town, 1866 and 1872.

[9] Met. Obs. Royal Obs., Cape of Good Hope, by Sir Thos. Maclean.

[10] Fort Columbus, U.S. Army Medical Reports, 1856.

[11] Beardmore, "Manual of Hydrology."

[12] Minutes of Proceedings Inst. C.E., vol. xxxi., 1820–69; Met. Soc., 1869-72.

[13] Mr. Symons, checked by "Smithsonian Rain Tables," 1872.

[14] Monthly notices Met. Soc. of Mauritius.

TABLE VII.—GIVING the ACTUAL RAINFALL during

Place.	Average.	Maximum, 1828–30.		Minimum, 1832–34.		Maximum, 1836–38.	
		Inches.	Totals.	Inches.	Totals.	Inches.	Totals.
	Inches.						
Calcutta	66·75	..	..	..	..	45·39 43·61 52·99	141·99
Bombay	76·80	121·98 65·65 71·86	259·49	74·09 71·39 70·47	215·95	87·99 64·58 50·78	203·35
Madras	48·60	37·89 36·87 32·43	107·19	18·45 37·12 39·00	94·57	44·68 49·26 52·33	146·27
Nágpúr	37·53	..	..	..	..	..	..
Mauritius	42·95	..	..	..	..	..	..
Barbadoes	56·07	..	..	..	..	..	..
Adelaide	21·80	..	..	..	..	..	..
Hobart Town . . .	22·71	..	..	..	..	..	..
Cape Town	24·21	..	..	..	..	..	..
New York	42·77	..	..	..	..	27·57 65·51 41·90	134·98
Rome	30·18	18·00 34·30 28·60	80·90	22·80 26·00 13·00	61·80	30·80 25·10 31·40	87·30
Greenwich	25·04	31·50 25·20 27·20	83·90	19·30 23·00 19·60	61·90	27·10 21·00 23·80	71·90
New Bedford, U.S. . .	41·40	36·00 58·10 57·50	151·60	43·80 37·90 40·10	121·80	38·10 34·70 34·00	106·80
Prague	16·44	..	..	10·88 19·35 10·13	40·36	16·63 18·63 16·00	51·26

the Maximum and Minimum Sun-Spot Periods.

Minimum, 1842–44.		Maximum, 1847–49.		Minimum, 1854–56.		Maximum, 1859–61.		Minimum, 1865–67.	
Inches.	Totals.	Inches.	Totals.	Inches.	Totals.	Inches.	Totals.	Inches.	Totals.
76·11 63·34 73·86	213·31	72·36 58·69 70·51	201·56	66·47 70·46 64·23	201·16	68·66 52·61 89·19	210·46	61·58 65·74 72·73	200·05
95·16 59·27 65·40	219·83	67·31 73·42 118·88	259·61	89·79 35·10 71·08	195·97	81·84 74·65 106·08	262·57	73·46 92·39 73·57	239·42
36·48 50·28 65·36	152·12	80·99 54·76 39·81	175·56	43·20 32·32 46·99	122·51	55·14 27·64 37·18	119·96	41·86 51·39 24·37	117·62
..	..	..	..	48·40 24·04 44·33	116·77	29·48 44·50 40·89	114·87	38·16 41·01 53·72	132·89
..	..	..	..	39·45 42·66 46·23	128·34	56·87 45·17 68·73	170·77	44·73 20·57 35·97	101·27
..	..	42·48 62·85 53·04	158·37	45·11 73·53 46·37	165·01	55·08 60·44 71·07	186·59	..	..
20·32 17·19 16·88	54·39	27·61 19·74 25·44	72·79	15·35 23·15 24·92	63·42	..	..	..	..
23·60 13·43 26·25	63·28	14·46 23·62 33·51	71·59	30·56 18·25 22·73	71·54	23·31 21·05 28·19	72·55	23·07 23·55 22·27	68·89
26·27 24·82 18·78	69·87	22·38 23·25 24·62	70·25	20·05 24·57 19·48	64·10	36·72 29·12 25·44	91·28	18·67 19·21 22·96	60·84
32·98 41·37 36·38	110·73	64·85 36·80 31·74	133·39	..	..	..	..	..	..
32·90 21·30 30·60	84·80	31·60 25·40 20·60	77·60	18·80 32·30 28·30	79·40	..	..	..	..
22·60 24·60 24·90	72·10	17·80 30·20 23·70	71·70	18·70 21·10 22·20	62·00	25·90 32·00 20·30	78·20	28·60 30·10 28·50	87·20
34·60 45·00 36·20	115·80	40·80 36·20 32·40	109·40	..	..	..	..	..	..
9·50 17·53 23·68	50·71	23·36 16·98 15·80	56·14	16·45 17·74 14·97	49·16	19·18 20·65 16·55	56·38	12·15 17·58 15·57	45·30

TABLE VIII.—GIVING the ACTUAL and TOTAL RAINFALL at FIVE PLACES during the SIX MAXIMUM and MINIMUM SUN-SPOT PERIODS, from 1836 to 1867.

Place	Average.	Maximum, 1836–38.	Minimum, 1842–44.	Maximum, 1847–49.	Minimum, 1854–56.	Maximum, 1859–61.	Minimum. 1865–67.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Calcutta	66·75	141·99	213·31	201·56	201·16	210·46	200·05
Bombay	76·80	203·35	219·83	259·61	195·97	262·57	239·42
Madras	48·60	146·27	152·12	175·56	122·51	119·96	117·62
Greenwich	25·04	71·90	72·10	71·70	62·00	78·20	87·20
Prague	16·44	51·26	50·71	56·14	49·16	56·38	45·30
Total and Average Total	689·23	614·77	708·07	764·57	630·80	727·57	689·59
Difference above or below the Average Total .		−74·46	+18·84	+75·34	−58·43	+38·34	+0·36

Table IX.—Giving the Actual and Total Rainfall at Seven Places during the Four Maximum and Minimum Sun-Spot Periods, from 1847 to 1867.

Place.	Average.	Maximum, 1847–49.	Minimum, 1854–56.	Maximum, 1859–61.	Minimum, 1865–67.
	inches.	inches.	inches.	inches.	inches.
Calcutta	66·75	201·56	201·16	210·46	200·05
Bombay	76·80	259·61	195·97	262·57	239·42
Madras	48·60	175·56	122·51	119·96	117·62
Hobart Town . .	22·71	71·59	71·54	72·55	68·89
Cape Town . . .	24·21	70·25	64·10	91·28	60·84
Greenwich . . .	25·04	71·70	62·00	78·20	87·20
Prague	16·44	56·14	49·16	56·38	45·30
Total and Average Total . . .	845·89	906·41	766·44	891·40	819·32
Difference above or below the Average Total . . .		+60·52	−79·45	+45·51	−26·57

Table X.—Giving the Actual and Total Rainfall at Nine Places during the Three Maximum and Minimum Sun-Spot Periods, from 1854 to 1867.

Place.	Average.	Minimum, 1854–56.	Maximum, 1859–61.	Minimum, 1865–67.
	inches.	inches.	inches.	inches.
Calcutta	66·75	201·16	210·46	200·05
Bombay	76·80	195·97	262·57	239·42
Madras	48·60	122·51	119·96	117·62
Nágpúr	37·53	116·77	114·87	132·89
Mauritius	42·95	128·34	170·77	101·27
Hobart Town	22·71	71·54	72·55	68·89
Cape Town	24·21	64·10	91·28	60·84
Greenwich	25·04	62·00	78·20	87·20
Prague	16·44	49·16	56·38	45·30
Total and Average Total .	1080·69	1011·55	1177·04	1053·48
Difference above or below the Average Total		−69·14	+96·35	−27·21

Mr. Bateman said he had listened with great interest and pleasure to the Paper, as it showed how much the Author, who was an old pupil of his own, had benefited by the opportunities of studying the question of providing for the various contingencies with which the water engineer had to contend in constructing waterworks of different kinds. It also showed, to those who had not been accustomed to investigate such problems, the vast number of circumstances that had to be taken into account before an accurate estimate of the yield of districts, or of the works to be executed, could be arrived at. The Nágpúr Waterworks seemed to have been carefully designed with reference to the particular conditions under which they had to be constructed, every difficulty having been foreseen and carefully provided for. The escape of water, the retention of the water by embankment, the means by which the water should be discharged through pipes, the protection of the pipes that they might not break by unequal pressure, and other details, had been carried out with perfect success. But by far the most important part of the Paper consisted of the record of the Author's observations upon the great variations in the rainfall in various parts of the country, and in different seasons, whether at the commencement of the wet season, or at its termination. Mr. Binnie had supplied a table, with diagrams, showing the rise and fall of the rain, and the deviations from the mean occurring at different periods of the year. He would draw special attention to a point of great importance, not only in its bearing on the supply of water, but likewise in all cases where a free passage of water had to be provided for, namely, the amount of water flowing off the ground under certain circumstances. It had been his lot to investigate the subject to a great extent. In steep hilly districts, where the streams were short, receiving the water falling upon mountain ranges, and where the rainfall was 2, 3, or 4 inches in twenty-four hours, floods were common of about 25 cubic feet, and occasionally up to 40 feet, and even 50 cubic feet per second to every hundred acres. On three occasions referred to by Mr. Binnie during the monsoon of 1872, extending from June to October, it appeared that the quantity of water flowing off the ground amounted to between 70 and 80 cubic feet per second per hundred acres, being nearly twice as much as the heaviest floods in the ordinary mountain districts of this country. He referred especially to the Pennine chain of hills between Lancashire and Yorkshire, where the average rainfall was about 40 inches. He was quite aware that in Cumberland and Westmoreland, where the fall was almost tropical, amounting to between 100 and 200 inches in a year—in such a valley, for instance, as Borrowdale, leading to Derwentwater,—the quantity of water flowing down would probably equal the 70 or 80 cubic feet per second per hundred acres falling at Nágpúr; but after it reached Derwentwater it was moderated; the large surface prevented its flowing from the lake as rapidly as it flowed into it. The water discharge in great areas of country which might be inundated by the overflow of rivers or the flowing from lakes, although they were fed by mountain ranges, was much smaller in volume than in the hilly districts themselves. For instance, the rain at the head of Loch Katrine was occasionally as much as 118 inches in the year, and more than that upon the mountains ascending towards the summit; but the heaviest flood from Loch Katrine itself gave but 12½ cubic feet per second per hundred acres—not more than half the flood on the range of hills between Lancashire and Yorkshire. From Loch Lubnaig, in the adjacent valley of the Lenny, draining an equal area to that of Loch Katrine and Loch Venacher, but where the average was not so great for impounding water as in the valley of Loch Katrine, the floods were slightly greater. In the valley of the Clyde, where a large quantity of land was inundated before the water could be discharged to the sea, the heaviest floods did not amount to more than 10 cubic feet per second per hundred acres. He drew attention to these facts (which were well ascertained, and not mere speculations) because of their importance in regard to the determination of the dimensions of bridges, whether in the case of roads or railways, with floods passing beneath them. Where the whole of the water of a district had to be stored for waterworks purposes, and the water was collected by flood water-courses or "catch-water" works, it was necessary that the channels by which the water was conveyed should be large enough to convey the heaviest floods that might occur; otherwise the rain water would be lost. On these subjects the Paper contained an amount of valuable information well worthy the consideration of all persons engaged in similar works. The Author's calculations as to the space required in order to store the average quantity of rainfall were very valuable. But in this country no attempt was made to effect this, although there were cases in which the amount of storage was so large (as in the case of some lakes and excessively large reservoirs), that nearly, if not quite, the average quantity of water might be collected if a regular quantity were drawn away. If less than the average were drawn, of course when the reservoirs were full, the difference between what was drawn and the average must necessarily run to waste. But no engineer who was careful to secûre the success of his works, ever calculated upon collecting as much as the average rainfall. He considered what might be reasonably calculated upon in two or three consecutive dry years, and made the capacity of the reservoir sufficient to last over the longest drought that might occur. Of these there were many records in this country, and they varied greatly according to the districts. Droughts lasting two hundred and forty days were not uncommon on the eastern coast of England; while one hundred and eighty days might be taken as the maximum on the western coast. Again, a smaller amount of rain required a smaller amount of storage than a large amount of rain. All these calculations had to be taken into account, and carefully determined, before an engineer could be said to have designed works satisfactorily to himself, or to those interested in the water to be supplied. The loss also, not only by vegetation, but by evaporation, which Mr. Binnie said amounted on an average to $\frac{1}{5}$ inch per day during a long drought in India, was a matter of serious consideration in the case of works designed for so hot a climate. In England he believed the evaporation through a long drought was only about $\frac{1}{10}$ inch per day. The loss also by vegetation and absorption varied considerably according to the nature of the country—whether, for instance, it was so steep that the water would flow from it as from a house-roof, or so flat that it would scarcely escape at all. But, as the Author had shown, this depended more upon the capacity of the air for absorbing moisture than upon the temperature of the air. The air might be so humid as to be just upon the point of precipitating rain, in which case no evaporation took place; or it might be so dry as eagerly to absorb moisture, and then evaporation was great. He had himself observed some years ago, that, during the prevalence of an easterly wind, 5 inches of snow (equal to about $\frac{2}{3}$ inch of rain) were taken up by evaporation in about three weeks, although the thermometer was below freezing point.

Major W. R. JOHNSON said he had lately been concerned in the restoration and improvement of the tank system in the Mysore country, in which there were no less than thirty thousand reservoirs, and in carrying out this work, it had been necessary to consider the proportion of rainfall running off the ground. No accurate data were forthcoming, but from rough observations made from works in action, it was assumed at starting that not more than one-fourth of the rainfall on an average found its way into the reservoirs. In one district in which the soil was light and sandy, and the greater proportion under the plough, even this was much in excess, and the proportion had there been reduced to one-sixth. In reference to the collection of surface drainage, the nature of the soil, and the condition of the surface, were the first points for consideration. There being a great scarcity of water in the city of Mysore, he had been sent to inquire into the matter, and had ascertained that the tanks formerly filled much more readily than at present. On examination he found that cultivation had much increased in the catchment basin; what was before hard, barren land having been ploughed up. After heavy rain, not a drop of water found its way into some of the supply or drainage channels, the whole having soaked into the ploughed land. He accordingly recommended that, in order to increase the water supply, the land in the catchment basin should be thrown out of cultivation. Accurate surveys were now, for the first time, being made of the drainages and reservoirs in Mysore; and as they were extensive, he trusted that valuable data would shortly be available.

The action of tanks as flood moderators was much more complete and apparent in a system of tanks than in isolated works. When the tanks were situated one above the other in chains, each acted as a moderator to that below, and absorbed, not only so much of the rainfall as they were capable of retaining, but also the excess, which would be distributed over their greatest area of water spread above their weir level, and escape gradually to the tanks below, from which in turn it would be passed off still more slowly to the next in succession, and so on. The result of this was that the rain that might fall in an hour, and but for these tanks would escape nearly as rapidly in a flood, might take days, and even weeks, to pass off, the quantity in excess of the capacity of the reservoirs being absorbed and distributed above the weir levels of each, and transferred slowly and harmlessly. Owing to this, the terminal tank of a series, although having a greater catchment basin, often required a less length of waste weir than tanks above it.

Dr. Pole was glad some data had been given on the subject of evaporation, which was obscure, both practically and theoretically. Practically, there were but few trustworthy facts on record, and it was interesting to know what occurred in India, where the heat and the dryness were often excessive. The data given in the Author's tables appeared to be deduced by a somewhat complex method, but still they were valuable as expressing results on a large scale. Theoretically, the knowledge of the subject was chiefly due to John Dalton, who had prepared tables for calculating the evaporation under different circumstances; these tables had been often reprinted, and he was not aware that any subsequent investigations had either, on the one hand, invalidated them, or, on the other hand, had added anything important to them. The tables were, however, somewhat troublesome to use in consequence of their peculiar form, and he had endeavoured to find a formula that would bring them into a more convenient shape. Mr. Bateman had stated that the rate of evaporation depended not only on the temperature, but also on the degree of dryness of the air. Dr. Pole would add a third condition that also materially influenced the evaporation, namely the wind, for it was found that evaporation proceeded much more rapidly under a brisk wind than when the atmosphere was calm. Combining these three elements, he had found that the results of Dalton's tables might be roughly represented by a formula as follows: if T = temperature of the atmosphere in degrees Fahrenheit; t = the *dew point*, or the lower temperature at which moisture began to be deposited (and which, when compared with T, showed the state of dryness of the atmosphere); V = velocity of the wind in miles per hour; E = evaporation in inches per diem from a water surface; and A a certain numerical coefficient, then,

$$E = \frac{T^2 - t^2}{A\,(100 - W)}.$$

The value of A would be about 80 for high or summer temperatures, increased to about 100 for low or winter ones. The formula was, he must state, purely empirical, and only professed to give a rough approximation to Dalton's results, in a somewhat more convenient form.

Dalton's tables did not provide for the case where the temperature of the water differed materially from that of the air; probably, according to the experiments of Mr. Dines and others, in this case T should be made to represent the temperature of the water surface, not that of the atmosphere.

He had endeavoured to check Mr. Binnie's evaporation results by Dalton's rules, and although there was some difficulty in making the comparison, owing to the dew point not being given, he found a tolerable agreement in the earlier portions of the table; but the later ones he thought were too low; for under the great heat and dryness marked in some of the lower lines, the evaporation might be expected to be greater than was there given, unless there were exceptional circumstances, not explained.

Dr. Pole believed that experiments on a large scale on evaporation, both from water and land surfaces, were much to be desired, and that any engineer who had the opportunity, and would take the trouble to carry them out efficiently, would be doing a great service, not only to the engineering profession, but to science in general.

Mr. Rogers Field said he had taken great interest in the subject of evaporation, on which, during the last three or four years, he had been carrying out a series of experiments for the Royal Society. He could confirm Dr. Pole's statement as to the want of reliable information on the subject. The records of meteorologists were for the most part worthless. The evaporator employed was generally nothing but a small metal vessel, which, when exposed to the sun, heated the water so much that an abnormal amount of evaporation was obtained, not in the least agreeing with the amount of evaporation taking place from a natural water surface. From preliminary experiments, a few years ago, he was led to suspect that that was the case; he had therefore sought the means of ascertaining the real evaporation from a large surface of water. He had buried in the ground an iron tank 6 feet square and 2 feet deep, and employed an apparatus which would measure the evaporation from it to the hundredth part of an inch—of course taking the rainfall into account. Using the tank as a datum, he had compared with it the evaporators recommended by different authorities, and the result was that the evaporation from them was two or three times the amount obtained from the tank. The amount obtained from the small metal vessels was 40 to 50 inches per annum; while that obtained from the tank was 18 to 23 inches only. As to the mode of calculating the evaporation, he thought that the formula of Dr. Dalton was the correct one. The most convenient mode was to take the elastic force of vapour at the temperature of the water, from that to subtract the elastic force of vapour at the temperature of the dew point, and multiply the difference by a constant, which would give the result in inches per diem: roughly speaking, this constant multiplier was one-half. Of course the wind and other circumstances would affect the result; but he did not think that there were sufficient data available at present to found a formula with regard to these points. There was no question, however, that evaporation increased as the wind increased, so that with much wind the multiplier would be greater than one-half. In Mr. Binnie's table the first datum was wanting, viz., the temperature of the water; but it might be assumed, from what had been stated, that it was the same as the temperature of the air. On that assumption he had calculated what the multiplier would be in the different periods. The first three periods, from October to November, from November to December, and from December to February, gave very nearly the same multiplier, viz., 1·00; and the other four periods gave multipliers varying from ·36 to ·50, and averaging ·42—not quite a half. He could not help thinking, with regard to the three first periods, that the data were not complete. Under ordinary circumstances in nature, as far as his experience went, a multiplier as high as 1·00 was not obtained; he therefore imagined that in the three periods referred to the temperature of the water was higher than the temperature of the air, or that some data were missing. The multipliers given by the last four periods, on the other hand, agreed very closely with those obtained from his experiments. Great service would be done to meteorological and hydraulic science if these experiments were carried further, including observations on the temperature of the water at the surface. The temperature mentioned in the Paper was at 5 feet below the surface. This might occasionally differ considerably from the temperature at the surface, which was what had to be taken into account in calculating the evaporation.

The ASTRONOMER ROYAL, Sir G. B. AIRY, said he was not prepared to enter into the engineering question, but he desired to say a few words on the concluding portion of the Paper, with reference to the possible relation between the spots on the sun and the amount of rainfall. The subject had engaged the attention of the Board of Visitors of the Royal Observatory, who some time since applied for a regular photographic register of the spots on the sun. This had been arranged after considerable delay, and he hoped that the observations would cast light upon the subject. The suggestion, that the amount of rainfall might depend upon the visible state of the sun's surface, naturally led to the idea that it might be connected with the amount of heat radiated directly from the sun, which was measurable by other means. For examining in some degree the supposed connection between the state of the sun's surface and the amount of rain, it might be advantageous to compare the observed intensity of heat radiating from the sun with the registered rainfall. To ascertain the intensity of the radiant heat, there was at the Royal Observatory at Greenwich a thermometer, with blackened bulb inclosed in an exhausted glass sphere, exposed to the rays of the sun, whose maximum reading was taken every day. This thermometer was brought into action, experimentally, in 1860; but from 1861 the observations had been taken, under the superintendence of Mr. Glaisher, on a uniform system; and it appeared best to commence comparisons on that year. The rainfall was measured by an extensive series of rain-guages.

On considering the applicability of the black-bulb readings to the subject before the Institution, it appeared unadvisable to adopt the mean of the daily readings for any length of time as a measure of the sun's radiant power. In this inquiry, it was not a question of measuring the sun's heat as it reached the earth through clouds, but, as nearly as possible, to measure the heat as it would come from a perfectly pure sky. In the following comparison, therefore, only the highest reading of the black-bulb thermometer in each month was used; there was, however, placed in the same table the mean of the readings for every day in each month. For the rain, the aggregate of rainfall through each month must be taken. This operation being completed for each month, the means of the monthly means of blackened thermometer, and the aggregates of monthly aggregates of rain, were taken for each year. Then the years were arranged in the order determined by the order of thermometer-means. Thus the following table was formed.

Year.	Yearly mean of highest thermometer-reading in each month.	Yearly mean of all thermometer-readings in each month.	Total rainfall in each Year.
	°	°	inches.
1864	101·8	79·2	16·38
1863	103·4	84·6	19·67
1862	109·4	83·7	26·45
1861	113·6	89·0	20·56
1869	116·5	90·4	24·02
1867	118·2	91·0	28·46
1865	118·3	94·0	28·70
1871	119·4	93·1	22·30
1870	122·1	93·3	18·55
1873	123·2	94·3	23·36
1872	124·3	97·8	30·02
1868	125·6	98·9	25·15
1866	126·4	95·0	30·72

The means of the yearly results in each group gave the following results:—

Means of highest thermometer-readings in each month.	Means of annual rainfalls.
°	in.
102·6	18·03
113·2	23·68
118·6	26·49
124·3	25·56

Thus it appeared—what he should not have supposed if he had not been led by the Paper to look into the matter—that the more scorching the sun, the greater was the quantity of rain that fell. The general correspondence of high readings of the black-bulb thermometer and large rainfalls was remarkable. There were, however, some anomalies in the details which made it imprudent at present to draw from this apparent correspondence any absolute conclusion. This caution was not without reason, for he had observed many instances in which a law seemed at first to be followed out, but had afterwards to be set aside. An instance of this was the supposed law that the daily phenomena of magnetism recurred in periods of ten or eleven years, a supposition which had been entirely negatived by an extended series of observations at Greenwich. The same thing might occur with regard to the figures cautiously cited by Mr. Binnie. One circumstance would not be forgotten, namely, that in different parts of the earth the fluctuations of rainfall had different orders. There appeared, however, to be, from 1861 to the present time, a distinct connection between the scorching of the sun and the amount of rainfall. It was only by following up these observations that the truth in such obscure matters could be ascertained.

Mr. G. Dines was surprised to learn that a place in British India, within the tropics, did not appear to have a much greater amount of rainfall than was experienced in Great Britain at the same elevation. He had made numerous experiments on the subject of evaporation, the result of which would be found in the proceedings of the Meteorological Society for November 1870,[1] where he had attempted to show the principles on which evaporation depended, the uselessness of the gauges ordinarily employed, and the reasons of their failure. He had taken up the matter as an amusement; but to engineers connected with hydraulic works it must be of the greatest importance. There was no reason why there should not be returns of daily evaporation from many places in England, as regular as those connected with the rainfall. He had long thought that the amount of evaporation in tropical countries had been overestimated, but had had no opportunity of testing the truth of that opinion until a short time since, when Captain Toynbee sent him a Paper in which the temperature of the sea and also of wet and dry bulb thermometers near the tropics were given. From the figures in that Paper he had calculated the amount of evaporation at 55 inches, so far nearly agreeing with Mr. Binnie's observations. Mr. Field had found it difficult to reconcile the figures in the upper part of one of the tables with those in the lower part. Mr. Dines differed from him as to which figures were correct; but possibly they might both be wrong, and Mr. Binnie might be right. It appeared from the table that the amount of evaporation with a mean temperature of 74° was greater than with a mean temperature of 92°. High temperatures warmed the surface of the water, but he was not sure whether they did not retard rather than promote evaporation; and he had no hesitatation in saying that, supposing the temperature of the water to remain constant, the evaporation on a cold windy day would be much greater than it would be under the burning sun of the tropics in calm weather. Evaporation was greater when the air was dry than when it was moist, as might be expected. Whenever the air was dry the dew point was low. In his opinion the amount of evaporation was proportional to the difference between the tension of vapour at the temperature of the water and that of the dew point. That was nothing more nor less than the old law of Dalton. Experiments he had made with water, varying in temperature from 180° downwards, and with evaporation amounting from 11 inches in a day down to nothing, proved, almost to a certainty, the correctness of that law. The equation $x\ (w - d) = \mathrm{E}$ represented it in a simple form, in which w represented the tension of vapour at the temperature of the water, d the tension of vapour at the temperature of the dew point, and E the evaporation. There was, however, one uncertain quantity in the equation which caused the difference of opinion between Mr. Field and himself, and which Dr. Pole had tried to remedy by a formula. That was the value of x. In a room with the doors and windows closed, x maintained its value steadily, but it was changed by the slightest movement of the air, and in his experiments he had found it vary from ·0118 to ·0742. In Dalton's table the value of x would be represented by the figures ·0336, ·0472 and ·0538. He thought the best experiments were those made by Mr. Greaves at the East London Waterworks, Old Ford, Bow. The only objection he had to them was that the water was not sufficiently near the edge of the vessel. He did not suppose that the temperature at Old Ford differed much from that at Greenwich, and the Greenwich tables gave all the figures that were necessary, if figures could determine the question. He had compared the experiments of Mr. Greaves with those tables, and had obtained a value for x varying from ·0190 to ·0594. He thought that the idea of being able to calculate the amount of evaporation might be abandoned. The lowest value he had obtained was on a warm, oppressive day. Dalton's law might be extended in this way. When the temperature of the water became lower than the temperature of the dew point, $w - d$ became a negative quantity, and E was negative. This was what occurred in practice. The moment the temperature of the water passed below the temperature of the dew point, evaporation ceased and condensation commenced on the surface of the water; and for 30° or 40° below the temperature of the dew point the same formula gave the amount of condensation. But he had found those experiments very difficult to manage. The vessel in which the water was contained was always covered with a non-conducting material; but he could never be certain whether moisture was not deposited on the outside of the vessel as well as on the surface of the water. The balances were similar to those used by analytical chemists. In one he put the weights, and in the other the vessel containing the water. He suspended a thermometer from the end of the beam, with the bulb just immersed in the water, and by noticing the time in which a fixed quantity of water evaporated he obtained the quantity of water evaporated at different temperatures. Out of doors his experiments were of a ruder character. It was insisted upon that the water in the gauge must be kept at the same temperature as the bulk of water from which evaporation was sought, and also that the water should be kept close to the edge of the vessel, so that it might get the full effect of the wind. In experiments with two vessels, in one of which the water was 3 inches below the edge, while the other was full, the evaporation from the former was 54 per cent. greater than from the other.

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[1] *Vide* Proceedings of the Meteorological Society, vol. v., p. 199.

He had prepared a chart of the London rainfall, month by month, for sixty years, on which he had marked the maximum and minimum periods of sun spots; but the results were of a negative character. In the "Philosophical Transactions" for 1801 would be found a Paper by Sir W. Herschell, in which the attempt was made to prove that the price of wheat in the Windsor market was influenced by the sun's spots.[1] The question had been lately revived by Mr. Meldrum, who thought that cyclones and the rainfall were influenced by the same cause. A communication had also been lately presented by Mr. Hennessey to the Royal Society, with a view to establish a connection between the rainfall at some place in India and sun spots;[2] and at the last meeting of the British Association it was argued that the amount of ozone was influenced by the same cause. His investigations led him to believe that, if the question was ever to be decided, it would not be by taking the rainfall at any one place, but by estimating it over the surface of the globe. It would be observed that in 1868–9 the rainfall at Nágpúr was 20 inches, 5 inches less than in London; while in Japan, at the same time, there was an exceptionally wet period, the amount of rain being 60 inches above any other year on record. If two independent workers had been investigating the matter at that time, one in Japan and the other in India, their conclusions would have been widely different.

Mr. RUSSEL AITKEN observed that in India the rains were affected by the smallest causes. Rocky or sandy ground, heated by the sun, kept off the clouds; but where the ground was covered with trees, the rain was much more abundant. In the island of Bombay, within a space of 3 miles the amount of rainfall differed 8 or 10 per cent. In the Western Ghauts, at Mahableshwur, the annual rainfall was 300 inches, while within 10 miles, at Pauchgunny, at the same level, the rainfall was only 50 inches; so that deductions from rain-gauges should be accepted with great caution, and only be regarded as applicable to small areas. The reservoir of which he had charge, the Vehar Lake, near Bombay, was practically a rain-gauge with an area of 2 square miles; and, although the results did not exactly agree with the records of smaller ones, he thought they would be interesting to the Institution. Mr. Conybeare, M. Inst. C.E., who constructed the works,[3] calculated the supply on the assumption that the annual rainfall would be the same as at a village 5 miles distant, where it amounted to 120 inches, of which he thought 74¼ inches could be secured, or $\frac{6}{10}$, being about the same proportion as was usually calculated for England. This, however, was not obtained. The area of the gathering ground was 3,515 acres, including the lake, of 1,260 acres. The lake overflowed the waste weir about every three years. In 1865, a year of average rainfall, the total amount of water impounded was 5,650,000,000 gallons, the recorded rainfall being 89 inches. He reckoned that between 20 and 30 inches of

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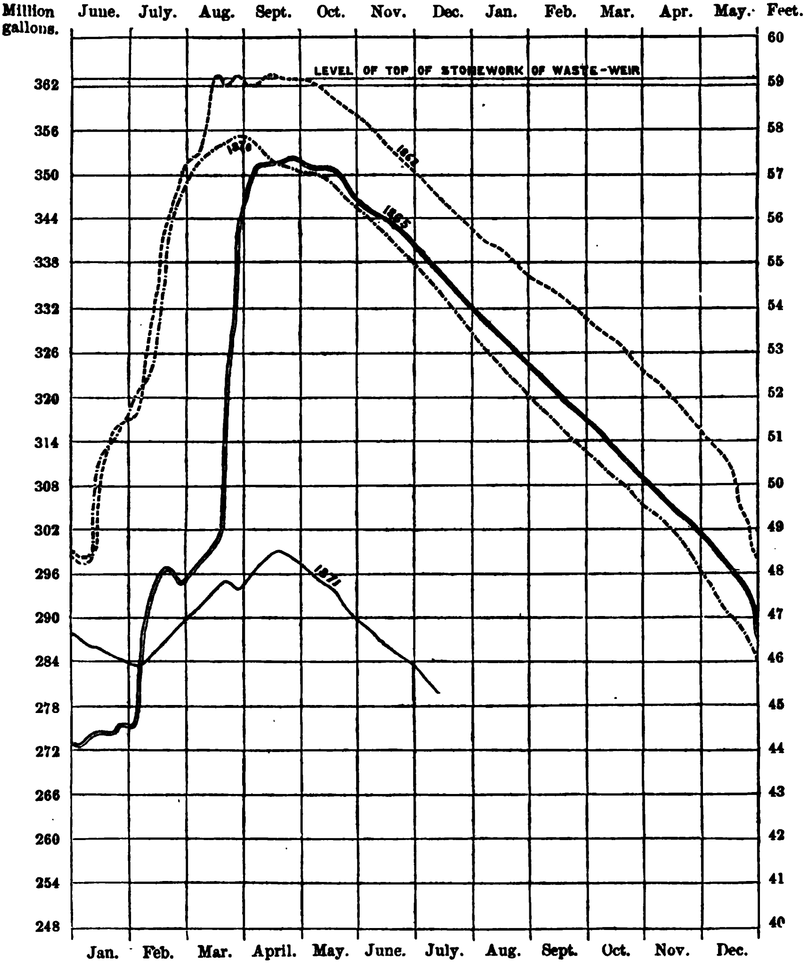
[1] *Vide* Phil. Trans. 1801, p. 313 *et seq.*

[2] *Vide* Proceedings of the Royal Society, vol. xxii. p. 286.

[3] A description of these works will be found in the Min. of Proc. Inst. C.E., vol. xvii. pp. 555–568.

FIG. 1.



Height of Water in Vehar reservoir, Bombay Waterworks.

the rainfall were absorbed by the ground and evaporated by the trees during each year. This amount would only apply to a gathering ground such as Vehar, of which the soil was soft, densely covered with trees and grass, and where the rain lasted about one hundred and twenty days on an average. In 1870, when the rainfall was 65 inches, the total amount collected in the reservoir was 4,400,000,000 gallons. This showed that about 75 per cent. of the rainfall from the gathering ground ran into the reservoir. In 1871, when the rainfall was exceedingly deficient, namely, 39 inches, the amount was 2,040,000,000 gallons, being only 50 per cent of the rainfall. The amount collected from the gathering ground in tropical countries, exclusive of what fell on the reservoir, and which was of course all impounded, might vary from 85 to 50 per cent. of the rainfall, and each case must be judged from the particular circumstances by which it was surrounded. The leakage, together with the evaporation from the lake, did not exceed 5 inches per month. He calculated the leakage from the various dams at 1½ inch; so that the evaporation during the dry weather, and he thought it would be the same during the wet weather, would be about 3½ inches per month, or 3½ feet per annum; a very different quantity from the 8 feet or 9 feet with which reservoirs in hot climates had been usually credited. Fig. 1 represented the height of water, at various times, in the Vehar Lake above the Puspolee datum. The figures on the left hand represented the capacity of the reservoir in million gallons for each foot of depth; those on the right, the gauge at the Vehar Lake tower. The reservoir was completed in 1859, and overflowed in 1861, 1863, 1866, and 1869. The rainfall in 1863 was 117 inches.

Mr. Greaves observed that the Nágpúr waterworks appeared to have been exceedingly well constructed. The extent of the gathering ground was inconsiderable, and the reservoir was proportionately rather large. It was to be hoped, for the sake of Nágpúr, that some other gathering ground was available; and if so, it would be well worth while to expend an additional £40,000 upon it. To have constructed such works for so small a sum was a marvellous feat. The value of the old dam was not stated; and possibly there was no expenditure on the gathering ground. He would ask whether the latter was so placed that it was not likely to be built upon—because a village in the midst of it might pollute the whole water supply? It would be well to ascertain whether some of the ancient reservoirs, bunds, and bridges in India might not be utilised. With regard to evaporation, he had discarded the idea of estimating it in a form applicable to engineering works by the use of wet and dry bulb thermometers, and he had contrived an instrument (which was exhibited) that would be applicable for continuous observations, and would give as useful a register of evaporation as a rain-gauge of rainfall. He agreed that gauges had hitherto been constructed on a wrong principle. They were made in a way to absorb the heat, and not so as to keep the temperature the same as that of the water. The gauge should be in a similar condition to a reservoir, pond, lake, or quiet river, and therefore would be best if consisting of a piece of the reservoir itself. The amount of evaporation in the neighbourhood of London was $\frac{4}{5}$ of the rainfall, and the question was as important as that of the rainfall. The influence of wind in promoting evaporation did not appear to have been sufficiently noticed, particularly in those countries where winds proverbially named hot were accustomed to blow. The desiccating power of those winds was, in his opinion, even greater than simple solar heat or local temperature.

Lt.-Col. A. STRANGE said that, though not a professional engineer, he might be allowed without presumption to bear testimony to the great care and skill with which the Paper had been drawn up. It afforded an interesting exemplification of the wide range of the duties of an engineer; for it passed, by a natural transition, from a matter-of-fact subject—that of the construction of a dam—to a subject in the region of speculative science, viz., the influence of the sun upon meteorological phenomena. It was evident that the sun was, directly or indirectly, the cause of almost every meteorological phenomenon; but hitherto, from various causes, the study of the sun had not formed a portion of the investigation of meteorologists. They appeared to have taken it for granted that, although the sun caused meteorological changes, it acted as a constant force, which might therefore be disregarded in the investigation. It was the inconstancy of the sun's action that was the question at issue. That had been studied to a certain extent, but as yet quite insufficiently. The Astronomer Royal had given an example of one mode of studying it by means of radiation experiments, which were valuable so far as they went; but they only formed a small portion of a large subject. It was natural that the sun's spots should form the first branch of the inquiry, as they were conspicuous, and underwent striking changes. As soon as it was announced, by persons of high authority, that the sun's spots were apparently periodical phenomena, going through their changes in a cycle of about eleven and a half years, it was natural that those who pursued meteorological inquiries should endeavour to detect a correspondence between those periods and the periods of meteorological phenomena, such as rainfall. He was not, however, one of those who accepted either the sun-spot period, or any of the uses to which it had been applied. In his opinion the observations had been quite insufficient to determine the period. They had been made with great care and by competent persons, but only in a few isolated places where there had been frequent interruptions from cloudy weather. There was nothing like an unbroken series of such observations in existence; and it was only from a continuous series that a satisfactory conclusion could be formed. The sun's spots might be of various kinds. Hitherto they had been treated as all of one kind, and the sum of their areas had been used to deduce the maximum and minimum sun-spot periods. Some, however, might be constant, while others might fluctuate. He could not admit that the sun's spots were necessarily the most efficient phenomena on the sun's surface to produce meteorological changes. They were the most conspicuous, but not necessarily on that account the most important. Before attempting to establish anything like a connection between the sun's changes and the changes on the earth, it was necessary to know the whole story with regard to the sun, and not only a small portion of it. The subject was as yet entirely in its infancy; and now that it was felt that a connection existed, though the terms of it could not be stated, it was important that the sun should really be studied with reference to that point. He was glad to find so great an interest taken in it by the members of the Institution, since it showed that the study of the subject had not only a philosophical, but a utilitarian value. He regarded it as the greatest and most difficult problem that science had now to solve, and he believed that its solution would be most fertile in its results. The study of the subject, however, would have to extend over some years, and it would not be wise to jump too readily to conclusions. What was required for the prosecution of this most pressing research was, that a number of suitable observatories should be established in localities so selected that clear weather might be expected always in one of them at least. By these means would be obtained the great desideratum of a record of the solar changes on every day throughout the year. Such a record would help to demonstrate not only that changes took place, but also how they took place—in other words, the law of the *modus operandi* might thus be detected. The great differences of climate existing in various parts of India at the same period of the year pointed to that country as peculiarly adapted by nature for such inquiries; and no part of the British dominions was more interested than India in a knowledge of the laws which governed meteorological fluctuations —laws which, when known, would doubtless afford indications when to expect excessive or defective rainfall, so important with respect to periodical famines—as also cyclones, and other phenomena affecting health, agriculture, and navigation.

Mr. T. ORMISTON said that when, seven years ago, he made an inquiry as to an auxiliary water supply for Bombay, and had occasion to examine into the question of evaporation, he applied for information to a gentleman the most competent to form an opinion, and who had experimented on the subject, Col. Fyfe, of the Royal Engineers, and Superintending Engineer for Irrigation in the Bombay Presidency. Colonel Fyfe stated that in large reservoirs —say 2 square miles in area—the amount of evaporation that he allowed for was about 3 feet per annum in the Deccan, and something less in the Concan district. From that, and from other information, he had put it down at 3 inches per month in the fair season, which lasted eight months, and half that amount in the rainy season, altogether 2½ feet per annum. Deducting that amount, and allowing the whole rainfall on the water area of the reservoir itself, and 55 per cent. to run off the ground, would give a tolerably fair approximation of the capability of the drainage valley. He found, however, that a considerable amount was lost by soakage and leakage through the dams. That of course would depend on the materials of which the dams were made, and the care with which they were constructed, as well as on the soil on which they were placed and on their height. Taking everything into account, he considered that by deducting ⅓ from the product the remainder would be available for distribution in the town. This mode of estimating the supply available for the Bombay district was approximately correct, and it was adopted by Major Tulloch, R.E., Assoc. Inst. C.E., in his report on the water supply of Bombay generally.[1] The question of evaporation was a very complicated one, depending upon a great many circumstances, one of them being the depth of water in the lake itself. In November last year, in Bombay Harbour, the thermometer being at 104° in the sun and 81° in the shade, where the water was 22 feet deep, the thermometer 2 feet under the surface showed 79°, and when it was only 4 feet deep, at the same level under the surface, 80°. Hence it would appear that a shallow tank would evaporate more than a deep one. He believed the works at Nágpúr had given the greatest satisfaction to all concerned. It might be open to question whether it would not have been more prudent to have taken the discharge pipe through the solid hill, instead of in a syphon over the bank, because, if a depression took place in the bank, it might be difficult to get at the pipe for the purpose of repairing it. There was one point to which the Author, with characteristic modesty, had not referred, namely, the closeness of the estimate with the actual cost. He had seen the estimate in an official paper, and it appeared to be within ½ per cent. of the actual cost of the work. Mr. Binnie had placed a formidable prospect before the younger members of the profession, who, he said, must not only be prepared to make general plans, designs, and estimates, but to make working drawings and sections, and drawings of all the plant, and also to carry out the works. Judging from his own experience, it was not so difficult after all to carry out works in India. He had had the charge of ten thousand workpeople there. The foremen proved clever and competent, if only they were made to feel that they had an interest in the matter. He had found it a great pleasure to exchange the management of work in England for that in India, where there was no fear of a deputation from a Union interrupting the men in their work. In India, if a man was not satisfied, he simply walked off, and did not even ask for his pay. The moral to be drawn from the Paper was, that the Government would have done well if, instead of founding a new college at Cooper's Hill for sending out young gentlemen to India, they had selected experienced assistants from English offices to carry out important works in that country.

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[1] *Vide* "The Water-Supply of Bombay. Being a Report submitted to the Bench of Justices of that City. By Major H. Tulloch, R.E. 8vo. Plates and Maps. London, 1872.

Mr. S. C. HOMERSHAM said that the amount (54 per cent.) lost by evaporation from the surface of the water, after it was collected in the lake or reservoir, seemed large. Another point worthy of attention was the temperature, 96° Fahr. in the river, and from 90° to 92° at 5 feet below the surface in the reservoir in warm seasons of the year. All who were connected or acquainted with works of that character knew that, even in this country, a great amount of animal life existed in surface water so impounded. Although here the maximum temperature of water in such reservoirs rarely exceeded 68° to 70° Fahr., yet in warm seasons one could not take a gallon of water from a stagnant lake, natural or artificial, without finding twelve or fourteen different species of minute animals and great numbers of each species, many of them very unwholesome; such things ought not to be found in potable water. Where lake or reservoir water was, as in India, at a temperature of 90° and upwards, there were still more of such animals—sponges and higher organisms, including the guinea-worm that attacked the bare legs of the water-carriers when wading in shallow water. Therefore, it was most desirable to do without surface water collected in large stagnant open reservoirs, more especially in a hot country like India, and to obtain subterranean water, which in its normal condition was uncontaminated with sewage or other organic matter, and quite free from living organisms. The amount of solid matter in the Nágpúr water was given at nearly 7 grains per gallon, one-fourth of which was put down as organic matter. This organic matter was, no doubt, mainly the residue of large numbers of animalcules; but it did not represent their entire weight. More than nine-tenths of living animalcules were water; so that when a chemist stated, as was usual, the amount of organic matter in a highly-dried state, or even burnt into charcoal from animalcules in water, that amount would have to be multiplied by ten to arrive at the weight of the animals when living. Mere chemical analysis of water, therefore, in regard to wholesomeness, might mislead; microscopical examination was also needed. The character of water had a great influence upon the health of a population, and living organisms in potable water were known to produce a large amount of disease or ill-health.

Sir **George Campbell** said he was not competent to discuss the scientific questions raised in the Paper: he would only remark that those who were connected with the administration of India had not been unmindful of the subject, but were doing their utmost to obtain all the scientific data possible in regard to the rainfall, the wind, and other matters. Many of the observations, it was true, were not altogether reliable; but at the large stations like Calcutta, Madras, Bombay, and Nágpúr, the various phenomena in connection with the rainfall, &c., had been observed with great scientific accuracy. He had the pleasure, before leaving Calcutta, of gratifying Mr. Blandford by arranging for a new meteorological observatory, which he hoped would be the means of adding to the valuable information already obtained. There was one point on which he had hoped that the discussion might have thrown light, viz., the possibility of storing large quantities of water under the conditions of soil and climate existing in India. That was a subject of great importance, not only in regard to the supply of water for such a town as Nágpúr, but in regard to the schemes of irrigation now before the Indian Government. The solution of the question had hardly even been approached. A

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very eminent man, Sir Arthur Cotton, had suggested the possibility of enormous reservoirs for the storage of water with a view to the perennial supply of canals to irrigate the country; but the plan had not been adopted on a large scale. True, there were in India tanks of considerable size which irrigated the ground immediately under them; there were also the remains of old tanks and reservoirs constructed under native rulers; but Sir Arthur Cotton's proposal was to do things on a much more magnificent scale. None of the existing tanks would suffice to supply a large irrigation canal flowing over hundreds of miles during many months of the year. It would be desirable to know whether such things were possible. He had himself had practical reason for believing it was necessary that the question should be solved. There were irrigation works in India which depended for their supply, not upon the perennial streams of the Himalayas, but upon the surface waters of the drier parts of the interior, in such districts as those in the neighbourhood of Nágpúr. He would refer, as an illustration, to part of the scheme known as the Orissa scheme, though it did not belong to Orissa. In Midnapore, which, during the recent famine, had been affected, not to the greatest degree, but to a considerable extent, by the drought, a canal had been completed, and, shortly before the drought, had been brought into operation. Up to that time the cultivators had not been induced to take the water freely; when the drought came there was a great demand for it, but the sources were dried up, so that the demand could not be supplied. The calculations on which the canal was based failed when it came to the pinch. The canal was calculated to supply from 100,000 to 200,000 acres, but at that critical period it could not irrigate more than 30,000 acres.

General F. COTTON said there was nothing to show that there was any practical impossibility in storing water to the extent required. In the south of India the ancient inhabitants had so completely turned to account the waters of the Viga, that it was only in exceptional years that it reached the sea. This stream got its supply from the never-failing western monsoon, and, though not one of the great rivers of India, was larger than any river in England. What had been done in the valley of the Viga might be worked for in the valley of the Ganges, &c.; and, comparing the skill and appliances of English engineers with the means at the disposal of the ancient Hindoos, it was not much to say that, had the ever-flowing water from the snow of the Himalayas been turned to account by modern energy, a great portion, if not all, of the suffering and loss from the recent drought in the

Ganges valley would have been avoided. He regretted that the subject, so vast and so important, should be touched upon on an occasion when it was impossible to discuss it.

Mr. G. J. Symons remarked that the only table in the Paper to which he had any objection was that of extraordinary showers during the monsoon of 1872. With perhaps two exceptions, the showers were not such as would be considered remarkable even in this country. It was true that the rainfall at Nágpúr was only 40 inches; but remembering the few months during which that amount principally fell, he scarcely thought that the showers in question deserved the term "extraordinary." Table VI., on the other hand, was one of the finest, perhaps the finest, of the kind ever compiled. It showed that the rule often adopted in this country, that the rainfall in the wettest season was twice that in the driest, did not hold good generally, as there were several cases where the maximum was more than three times the minimum. He entirely agreed with Sir George Campbell respecting the observations made in India at the present time, but in reference to the rainfall at Madras, as far back as 1813, it was not known how the records there were then kept. Curiously enough, nearly all the exceptional features were at Madras; and this was especially noticeable in regard to the minimum and maximum fall, the latter being 4¾ times the former. The "period of observation" in Table VI. varied from nineteen to sixty years. The limits of deviation would hardly be as great in a period of nineteen years as in a period of sixty years; he had therefore tried to ascertain whether there was any relation between the "extreme range" and the "number of years;" and he found that, among the instances quoted in Table VI., there was none whatever. With regard to the relation which the average fall of the three driest consecutive years bore to the average of a long period, there had been in this country two proposals. One was to take off from the mean one-sixth, which was the same thing as saying that the average fall in three consecutive dry years was 83 per cent.; but he[1] had taken it at 80, and this, whether right or wrong, was nearest to Mr. Binnie's figures. It had been said that continuous records were desirable, and he agreed with the observation. One of the stations cited by the Author was Barbadoes. It appeared, from a recent publication by Governor Rawson, that two registers had been rolled into one, as was frequently the case. By a separate record, 77, instead of 84, was obtained; showing the disturbing element introduced by a register that did not run on without a break. At St. Petersburg the average of three consecutive dry years was only 64 per cent. of the mean, but those were the first years of the register, thirty or forty years ago; and he was not sure whether the records were as reliable as the subsequent ones. He concurred in all that had been said by Colonel Strange with regard to sun spots. He thought it was a pity the Author had in Tables VIII., IX., and X. departed from the excellent plan adopted in Table VI., where the rainfall was given in terms of the mean annual fall, and a series of ratio values comparable with one another, but had gone back to the old plan of giving it in inches. With regard to evaporation, the temperature of the water was taken in the experimental tank, not only at the surface and at the depth of a foot, but also at the bottom; and, moreover, a series of thermometers were placed in a river at a short distance, in order to ascertain the exact relation of the temperature of the water in the tank to that of the large mass of running water. That relation was very close indeed, but with the ordinary evaporators, in each of which observations of temperature were made, there would be differences of 20° or 30°. An anemometer was also employed within a foot of the ground, and close to the water, to determine the influence of the wind on the amount of evaporation. It had been stated that the evaporation was a certain proportion of the rainfall; this he denied. There was no relation between the evaporation and the rainfall. He might be permitted to refer the younger members to the "Annales des Ponts et Chaussées" of France, which contained records of evaporation superior to any that he had seen elsewhere. The inutility of previous methods had been discovered, and other and better means had been adopted.

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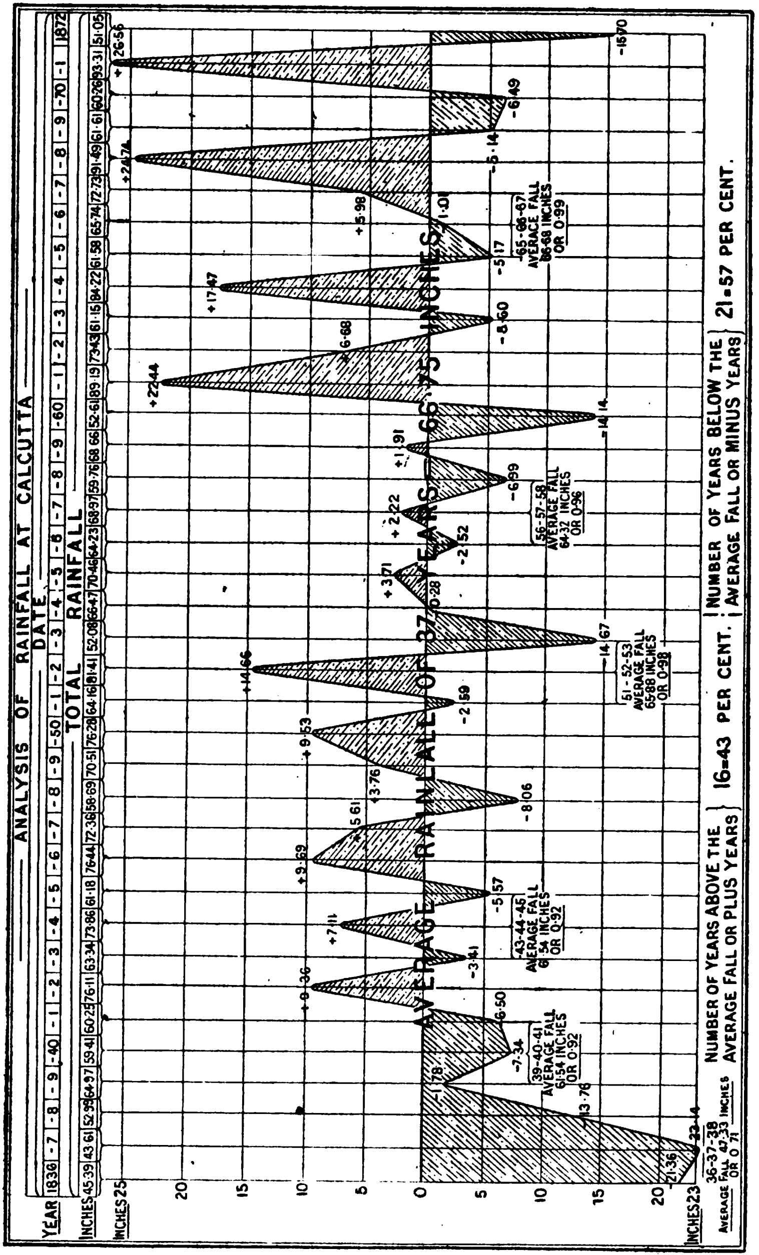
[1] *Vide* Royal Commission on Water Supply, 1868. Minutes of Evidence, p. 38.

Captain Saurin Brooke, ~~R.E.~~ B.S.C., Deputy Commissioner of Jubbulpore, wished to add his testimony to the success of these works. He had found from official records that the original estimate for the Nágpúr Waterworks was £36,554; a subsequent estimate for subsidiary works, not covered by the text of the first instructions, amounted to £2,981. The expenditure, as against the original estimate, amounted to £36,718, being an excess of £164 over the estimate—somewhat less than ½ per cent. This would be creditable in any country, and was especially so in India, where the difficulties arising from the want of trained supervision were very great, and not easy to overcome. On the supplemental estimate the expenditure amounted to £2,811, being £170 below the calculation. The net result on the two estimates was a saving of £6. The closeness of the estimate to the cost of the work would, he was sure, be duly appreciated, and was owing to the careful attention given, not only to the details of the work, but also to a rigorous supervision of the accounts. The municipality of Nágpúr might be congratulated on the successful issue of the undertaking—which was mainly due to having, under the guidance of Mr. Morris, the Chief Commissioner, selected a good man, and, without unnecessary interference, trusted him implicitly till the work was completed.

Mr. BINNIE, in reply, said the value of the old embankment, considered as earthwork, and priced at the same figure as it had cost to form the newly raised portion, would be about £1,800, which would bring up the total amount to £41,332. A tunnel round the end of the embankment was not adopted on account of the expense, notwithstanding that such a mode of discharging the water would have been most advantageous. From the experience gained in constructing the works, if he were again designing them he should make the lift of the syphon considerably greater. The drainage area was a rocky, uncultivable, almost treeless and uninhabited tract. The rough grass growing during the rains was partly burned off, partly cut for thatching, and partly grazed off, but no contamination was likely to arise from the latter cause, as the dung of the animals was carefully collected by the natives for fuel. A reference to the figures in Tables III. and IV. would show that the reservoir was not too large. It contained 240,000,000 cubic feet, a little under two years' supply, which he believed was a safe capacity for reservoirs in that part of India. Nor could the drainage area be said to be too small for the size of the reservoir. On an average, during the last twenty years (as shown in Table IV.) it discharged from 60,000,000 to 80,000,000 cubic feet of water per annum more than the reservoir, as at present constructed, could contain. On a review of the whole subject, he thought it would be better if the reservoir resembled instances 5 and 6 in Table IV., and held 48,000,000 cubic feet more than at present. Mr. Homersham had selected a most unfortunate example in illustration of his favourite views. In the case of Nágpúr, the subsoil water, as obtained from wells, was often brackish. In the city of Nágpúr out of twelve hundred and thirty-one wells, nine hundred were so salt that they were totally unpotable. He could not admit that the high temperature was likely to prove so deleterious as had been suggested, or that the whole of the organic matter was necessarily the remains of organic animal life; he believed a considerable portion of it was undeleterious vegetable matter, and, so far from the present supply affecting the health of the population, he was informed by the Sanitary Commissioner of Nágpúr that, since the introduction of the new supply, the health of the city had considerably improved. He agreed with Sir George Campbell as to the necessity for the construction of large reservoirs in India, and with General Cotton as to their perfect feasibility. Nor was it from any fault of the engineers in India that they were not constructed. Within the last few years, in a comparatively small district like that of the Central Provinces, he knew of two irrigation projects, both depending for their supply on large irrigation reservoirs. These had been sent up to the Government of India, but they were still unsanctioned. As the showers recorded in Table II. not being extraordinary, he thought it would be impossible to cite instances in this or any other European country of showers of 3½ inches in forty-five minutes, or cases in which there had been a discharge of upwards of 90 per cent. from a drainage area of 6½ square miles within three hours after the commencement of the shower. With regard to the yield from the drainage area, taking into account that the average rainfall at Bombay was 76·8 inches, and that the climate was more humid near the sea, he thought the observations of Mr. Russel Aitken, who found the flow from the ground to vary from 50 to 80 per cent., the percentage depending on the amount of the rainfall, fully bore out his observations. For in the exceedingly dry climate of Nágpúr, with an average monsoon rainfall of only 37 inches, he had found from actual gaugings the yield would vary from 15¼ up to 40 per cent., depending on whether the season's rainfall was 19 or 40 inches. The diagrams with regard to fluctuations of rainfall referred to by Mr. Bateman, of which particulars for Calcutta were given in Fig. 2, p. 58, formed the original basis on which Table VI. was constructed. They were too voluminous for publication in the Proceedings of the Institution, but he would take an early opportunity of presenting them for reference in the library. The subject of rainfall fluctuations formed the most valuable part of Paper, and he was sorry it was not more discussed, as, in his opinion, Table VI. showed some slight approach to a general law on the subject. With regard to the exceptional character of Madras, it might be explained in this way. Throughout India rains were generally due either to the north-east or the south-west monsoon. In ordinary years Madras received its rain from the north-east monsoon, but occasionally it got a little of the south-west, and sometimes

FIG. 2.


ANALYSIS OF RAINFALL AT CALCUTTA
DATE
YEAR 1836 -7 -8 -9 -40 -1 -2 -3 -4 -5 -6 -7 -8 -9 -50 -1 -2 -3 -4 -5 -6 -7 -8 -9 -60 -1 -2 -3 -4 -5 -6 -7 -8 -9 -70 -1 1872
TOTAL RAINFALL
INCHES 45·39 43·61 52·99 64·97 59·41 60·25 76·11 63·34 73·86 61·18 76·44 72·36 58·69 70·51 76·28 64·16 81·41 52·08 66·47 70·46 64·23 68·97 59·76 68·66 52·61 89·19 73·43 61·15 84·22 61·58 65·74 72·73 91·49 61·61 60·26 93·31 51·05
INCHES 25
20
15
10
5
0
5
10
15
20
INCHES 23
AVERAGE RAINFALL OF 37 YEARS 66·75 INCHES
-21·36
-23·14
-13·76
-1·78
-7·34
-6·50
+9·36
-3·41
+7·11
-5·57
+9·69
+5·61
-8·06
+3·76
+9·53
-2·59
+14·66
-14·67
-0·28
+3·71
-2·52
+2·22
-6·99
+1·91
-14·14
+22·44
+6·68
-8·60
+17·47
-5·17
-1·01
+5·98
+24·74
-5·14
-6·49
+26·56
-15·70
36-37-38 AVERAGE FALL 47·33 INCHES OR 0·71
39-40-41 AVERAGE FALL 61·54 INCHES OR 0·92
43-44-45 AVERAGE FALL 61·54 INCHES OR 0·92
51-52-53 AVERAGE FALL 65·88 INCHES OR 0·98
56-57-58 AVERAGE FALL 64·32 INCHES OR 0·96
65-66-67 AVERAGE FALL 66·68 INCHES OR 0·99
NUMBER OF YEARS ABOVE THE AVERAGE FALL OR PLUS YEARS 16=43 PER CENT.
NUMBER OF YEARS BELOW THE AVERAGE FALL OR MINUS YEARS 21=57 PER CENT.

a large quantity was blown across the continent of India. To that cause he attributed the great fluctuation between the extreme minimum and the extreme maximum which Madràs presented when contrasted with other places in India. The subject of evaporation had proved more interesting than he could have expected. The observations recorded in Table V. had been made without any preconcerted theoretical views. The facts were collected in the first five columns, and thus he endeavoured to deduce from them the actual amount of evaporation. The result of the discussion proved how little was known on the subject, and how much the most eminent authorities differed as to the formulæ, and as to the coefficients to be employed. Some gentlemen were able to reconcile the first three of the observations with theory, but failed to do so with regard to the four last, while others said exactly the reverse. All however, were agreed that some great and unexplained force was at work during one of the two periods into which the table could be divided. He did not profess to give all the data on which the theory of the subject depended, but he thought he could explain the matter. From about the middle or the end of March to the commencement of the rains in June, the hot winds blew at Nágpúr continuously, during the day, with a velocity of upwards of 150 miles per day. Their temperature averaged about 98°, and the comparative humidity of the air during that time was considerably under ·50, saturation being considered as 1. Of course, in judging of hot winds according to their scientific aspect, personal feeling must be set aside, but the effect on the ordinary senses, when stepping out from a cool room on to a verandah in the open air, was something like that experienced on going in front of a blast furnace. With regard to the apparent discrepancy between the first and last results in Table V., pointed out by Dr. Pole, it might be explained in this way. As stated in the Paper, during the dry season when his observations were taken, there was a fall of 3 inches of rain, which, in order to arrive at the average evaporation per diem, he had distributed over the whole season. Out of that quantity 1·40 inch fell during the period of the last observation, from the 7th of May to the 9th of June. Taking the 1·40 inch, and restricting it purely to that one observation, not distributing it over the whole series, it raised the amount of evaporation during that period from ·0157 foot to ·019 foot per day. Remembering how many circumstances entered into the consideration of the subject, such as the temperature of the air, the dew point, the force of the wind, the elastic force of vapour, the temperature and depth of the water, and other points mentioned during the discussion, he thought the time had arrived when, if the subject was to be thoroughly investigated, it would be necessary to give up observations with small vessels, such as those to which reference had been made; they were too shallow for reliable results as to temperature, too limited in area to allow free play to the wind, and were altogether so small as to be affected by many disturbing causes. He had endeavoured, however imperfectly, to indicate, by the facts given in Table ~~K~~ J, how, in his opinion, the observations should in future be conducted, and he believed that his own observations, extending over a water area of 350 acres, were much less liable to small errors and disturbing causes than in the case of the 36 square feet referred to by Mr. Field. No consideration of the subject of rainfall in the present day would be complete without mention of the sun-spot theory; and he was much pleased that so free and full an expression of opinion on the subject had been elicited. The knowledge that, by his remarks, so eminent a man as the Astronomer Royal had been led to consider the relation between solar radiation and rainfall was of itself a sufficient reward for bringing the subject before the Institution. With regard to the duties of engineers in India, he had stated, to the best of his ability, his own personal experience, and what he had himself seen in the case of engineers similarly situated. Mr. Ormiston, at Bombay, was differently circumstanced. He had contractors and a large trained staff, and could obtain easily and cheaply from Europe any materials he might require. If he were removed 500 miles inland, he would be thrown much more upon his own resources. While generally agreeing in the observations as to Cooper's Hill College, yet he had no hesitation in expressing his belief that it was the finest theoretical engineering school he had ever seen, and he believed that Government would in time see the necessity of enlarging the period to be spent by the students on actual works of construction under some eminent civil engineer. Experience was at the very root of the profession, and it could only be properly acquired on actual works under a good master. Personally, he was deeply indebted to Mr. Bateman for the training he had received: without it he never could have brought this Paper properly before the Institution, and he was sure that training could not have been received at any school or college, however good.

Mr. HARRISON, President, said the manner in which Mr. Binnie's observations had been received rendered it unnecessary for him to say a word as to the value of the Paper. It had been the means of laying before the Institution matters of considerable interest, and had brought among them their Honorary Member, the Astronomer Royal, who had propounded, not exactly a theory, but a striking coincidence in regard to the rainfall going *pari passu* with the heat of the sun. Although he called it merely a coincidence, he was about to devote his attention to the matter, to see whether there was anything in it that could be reduced to a positive theory. He could not allow the opportunity to pass without making a remark on a further coincidence, in regard to the works constructed by Mr. Binnie. That he should have submitted an estimate for a large work of that kind, and actually completed it within a few pounds of that estimate, was a circumstance that reflected upon him the greatest credit, and he only wished that in the numerous works executed in this country, engineers could lay claim to similar accuracy. He had not himself been engaged in the construction of reservoirs of anything like the magnitude referred to. Immense reservoirs and embankments, however, had been constructed in England, and if it could be shown that such enormous receptacles for water as had been alluded to were a matter of necessity in India, he believed the practical ingenuity, talent, and experience of engineers would not be wanting for carrying them out.

Mr. HENRY F. BLANFORD remarked, through the Secretary, that, in his opinion, India offered a fairer field for investigating the perplexed problem of rainfall, and, indeed, most other meteorological conditions, than any country equally accessible; and he hoped that the steps now being taken by the Indian government to systematise observation and to render the results accessible, would, in the course of a few years, lead to definite conclusions on the subject. He would add a few data to those given by the Author.

With respect to Calcutta, the recorded rainfall from 1829 to 1835 was as follows:—

	Inches.		Inches.
1829	59·94	1833	60·56
1830	63·28	1834	68·73
1831	56·90	1835	85·50
1832	50·72		

and that of 1873, not included in the table, was 45·27 inches. The average of the forty-five years was 65·44 inches, which differed but little from that of thirty-seven years given by the Author. The largest fall recorded within twenty-four hours was 12 inches. That quantity fell on the 11th of May, 1835, and again on the 13th of June, 1861. On the former occasion the whole fall took place in three hours.

The average rainfall of Nágpúr, according to his data (twenty-four years), was somewhat higher than that given by Mr. Binnie; it was—

	Inches.
From January to May	3·22
,, June to September	38·42
,, October to December	3·70
	45·34

The following data for the seven years, 1826–32, were given by Dr. Buist, in his "Manual of Physical Research for India":—

	Inches.		Inches.
1826	65·16	1830	33·00
1827	53·99	1831	65·31
1828	46·61	1832	37·14
1829	50·25		

Nothing was stated with respect to the position or character of the gauge used in these measurements; perhaps, therefore, the returns could not be accepted with perfect confidence. The average of these years, distributed according to the seasons as above, was—

	Inches.
From January to May	3·14
,, June to September	40·12
,, October to December	5·63

It was to be noticed that the high average of the last three months of the year was chiefly affected by the large quantity of 17·75 inches recorded in 1831, of which 8·24 inches fell in the month of December alone.

He did not think that at present any light could be thrown on the causes of the fluctuation of the rainfall in different years, and as yet no empirical law of any value had been discovered in its irregular incidence. But there seemed to be some prospect that the study of the distribution of pressure in the monsoon region would, in the course of time, throw some light on this perplexed subject. In a Paper communicated to the British Association this year, at Belfast, he showed that, as appeared from the barometric registers of the last six years, the irregularities of relative pressure in Northern India, regarded as deviations from the normal or average distribution of pressure for a given month or season, were frequently protracted, so that the same abnormal features of pressure-distribution frequently lasted through a whole monsoon;

sometimes, indeed, it would appear from the registers, through one or two years; but this required further verification. Moreover, in one or two cases, notably in the monsoon of 1868, and less distinctly in that of 1873, there appeared to be a definite relation between the position of the abnormal barometric depression and that of excessive and deficient rainfall respectively. Unfortunately, most of the barometric registers kept in India, till within the last few years, were worthless, the observations not having been corrected to any standard, and observers having neglected to ascertain the elevation of their instruments above sea-level, or any local datum level; so that it would require several years' observations to work out the laws suggested by the facts recently observed. As far as could be surmised at present, it seemed that it was at least as probable that deficient rainfall in one region was compensated by excessive rainfall elsewhere, as that the observed irregularities were general and simultaneous. At all events it would, he thought, be a mistake to direct attention too exclusively to the question of cycles, and to neglect inquiry into that of compensating areas, which to him seemed the more promising of the two. The monsoon region of South-Eastern Asia presented many advantages for such an inquiry, as it was (in India at least) cut off from Central Asia by the Himalayan chain, and had an independent wind system. It was to be hoped that systematised observation in India might lead to some more definite conclusions than had yet been attained.

With respect to an observation of the Astronomer Royal as to the apparent concurrence of increased solar radiation at the earth's surface, with increased rainfall, the Indian observations showed that the temperature of solar radiation was the higher, the drier the atmosphere and the smaller the rainfall.

November 17, 1874.
THOS. E. HARRISON, President,
in the Chair.

The discussion upon the Paper, No. 1,398, "The Nágpúr Waterworks," by Mr. Binnie, was continued throughout the evening.

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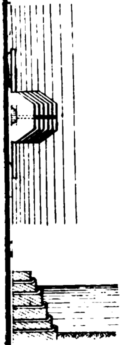
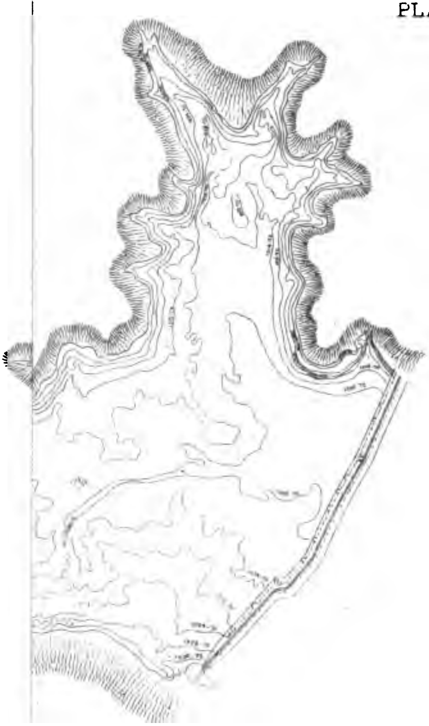
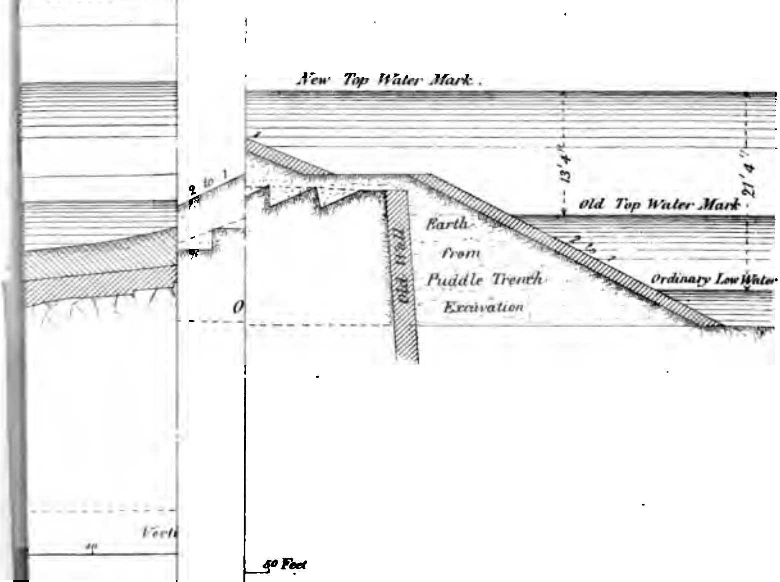
PLATE I.







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